Straw Insulation Materials to Address Heating Fuel Requirements, Thermal Comfort, and Natural Resource Depletion in Developing Regions

by

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ABSTRACT

In modern society, major stresses are placed on the natural environment in an attempt to make the location comfortable for the human occupants. For many developing regions with cold winters such as northern Pakistan, new building construction has been driven by structural and economic criteria. Thermal comfort can be improved, heating fuel requirements can be reduced, and degradation of the natural environment can be mitigated by improving the thermal performance of these buildings. This thesis presents strong evidence for the benefits of thermal insulation and presents an optimal solution for producing that insulation in a sustainable and cost-competitive manner.

Using Polymeric Methylene Diisocyanate as a binder, we were able to develop a formula for low density, structurally sound, straw based insulation board. The fabrication process involves the spraying of isocyanate onto an agricultural furnish of mixed fiber lengths in a rotating drum. The process appears to be one that could be used in developing regions. It is likely that this board can be manufactured well below the cost of competing insulation board products on a unit thermal resistance basis. Forty-one experimental boards were fabricated. The thermal, structural, and economic characteristics of these boards have been tested and analyzed. A formula has been developed for an optimized solution based on binder load, fiber size concentrations, density, and economic cost. The optimal boards meet or exceed all of our product design specifications.

The optimal insulation placement scenarios for community-built school buildings are explored through the use of a dynamic building thermal modeling software, SERI-RES. The work described in this thesis provides a strong foundation for moving ahead and improving the thermal performance of the schools. Installation of insulation will improve thermal comfort in schools that continue to be unheated or under-heated. For those schools that are more fully heated, insulation will reduce fuel use at no penalty in thermal comfort. Improved thermal comfort will extend the use of schools in winter and payback periods are of reasonable duration, from two to four years for heated schools.

Thesis Supervisor: Leslie Keith Norford
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Acknowledgments

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My advisors Les Norford and Leon Glicksman have provided me with a wonderful problem that has kept me fruitfully engaged in pursuit of a solution. They have helped to guide my MIT experience which has been a unique and a remarkable period of my life and for this I am grateful.

There have been many contributors to the success of this effort: my colleague Henry (Tim) Harvey who jointly carried out the insulation board research; Greg Sullivan who's thesis and thermal conductivity tester have provided a solid foundation on which Tim and I built our solutions; my colleague Jonathan Wright who conducted the site survey trip with me that has been a central source of data for this thesis; John Whitson who performed the majority of the structural tests; and Rahmat Ali, Karimulla Beg, and Nabeela F. Nazir of the Aga Kahn Housing Board for Pakistan who assisted us tremendously throughout the site survey trip and supplied cultural and economic data for this project. Additionally, I would like to thank ICI Polyurethanes Group, a business unit of ICI Americas Incorporated, who supported a partial research assistantship for me during the 1995-96 school year. They also facilitated the insulation board optimization experiment by donating equipment time and MDI expertise at their customer support facilities in West Deptford, New Jersey. Special thanks go to Tony Cunningham (ICI, Belgium), Bill Newman, Joe Marcinko, and the board process technicians at ICI.

I want to express my sincere appreciation to the American Society of Heating, Refrigerating, and Air-Conditioning Engineers Incorporated (ASHRAE) for their award of a generous graduate student grant-in-aid for the 1996-97 school year. Finally, I'd also like to thank Sigma Xi, The Scientific Research Society, for their award of a grant-in-aid of research during January of 1997.

Reflections on the unity of life

Yes, I have become a straw man. I have changed a great deal and worn all sorts of clothes but more than anything else I have stayed the same. I am pleased that one man's waste can serve so well as the bread and butter of another.

--Joseph Arons Charlson

1. Introduction

In the course of modernization, developing countries import a wide and often incomplete variety of technologies from foreign communities. In fact these imported "improvements" can lead to decreases in the standard of living. In building technology transfer, this can often be observed by decreased levels of thermal comfort or poor structural performance in locations that experience environmental extremes such as earthquakes or hurricanes. Poor thermal performance of buildings can be the outcome of a lack of information, suitable technology, and economic resources.

In countries with harsh winter conditions, there can be found a network of ill-effects related to poor thermal performance of buildings. This process begins with the necessity for burning wood resources for winter heating. The indoor combustion of wood results in increased levels of indoor smoke, leading to health problems such as upper respiratory illness. When wood resources are scarce and unavailable for combustion, feed stocks and fertilizers may be burned for the necessary heat. The allocation of these important byproducts to combustion can result in decreased yields from agriculture and livestock. In the environment, deforestation results in soil erosion, microclimate degradation, and contributes to a wide range of ecosystem-level problems such as species extinction. However, basic improvements in building thermal performance can mitigate the intensity of this deleterious process.

The work contained in this thesis includes two primary components to solving the problem of poor building performance during the winter months for northern Pakistan and other developing regions of the world. It is the intention of the author to present strong evidence of the benefits from utilizing thermal insulation in such regions and to present an optimized formula for an agriculture based insulation board that can be developed in a sustainable and cost-competitive manner. Part I covers the development and testing of straw-based insulation boards. The results of this effort indicate that an optimal solution has indeed been discovered. Readers interested only in reviewing the results of this development effort should proceed directly to Chapter 4, Thermal, Structural, and Economic Results with MDI, page 30. Part II covers the thermal analysis of the Self-Help Schools in northern Pakistan. Readers interested only in reviewing the results of the computer energy simulations can proceed directly to Chapter 9, Results of Computer Energy Simulations, page 125. The simulation results chapter is immediately followed by a chapter concerning recommendations for improving the thermal performance of these buildings. The thermal and economic modeling assumptions are reviewed in detail in Chapter 7, page 111.

Part I. Insulation Board Research

2. Overview of the Problem

In the Northern Areas and Chitral regions of Pakistan, wood resources are extremely scarce due to combined effects of deforestation, a mountainous topography, and an alpine desert climate. Many people spend one day per week gathering wood from the river for heating and cooking fuel. The houses and schools in these regions are built without regard to passive solar design considerations such as orientation and skyline obstruction profiles. The building materials used also have poor insulating properties. If this wood or other cellulosic heating fuel were diverted from combustion to manufacture insulation material, the heating fuel requirements to achieve thermal comfort will be greatly reduced

The three wall types commonly found in new construction are 8-inch wide hollow-core concrete block, 15-inch wide semi-dressed stone, and 12-inch wide terracrete block. Using a heat flux meter and mercury thermometers, I was able to make rough measurements of the thermal resistance values of the wall constructions.[1] The concrete block has a thermal resistance of 1.8 ft^2-hr-°F/Btu, the semi-dressed stone has a thermal resistance of 1.3 ft^2-hr-°F/Btu, and the terracrete has a thermal resistance of 1.7 ft^2-hr-°F/Btu. When used in conjunction with steel reinforcing bar, these constructions provide dependable seismic performance on single story structures. However, in terms of thermal performance, these buildings do not perform as well as the traditional dwellings. The result of such wall constructions in regions with cold winters and scarce heating fuel is cold and uncomfortable occupants. Indeed, the community-built (Self-Help) schools in northern Pakistan are generally closed from late-November until mid-February because of the cold conditions.

A comparison of modern and traditional building construction techniques in northern Pakistan reveals several differences that may affect the perceived thermal comfort of the occupants. The traditional walls are thicker and utilize boulders cast in mud-straw mortar. In the traditional homes, a visible layer of hydrocarbon deposits builds up on the inside wall from the daily fires. So once a year the occupants "wash" the walls with a fresh coat of mud plaster, adding to the overall wall thickness over time. The straw in the mortar, the increased wall thickness, and the mud-hydrocarbon plaster build-up, result in walls of greater thermal resistance. The traditional roof is also thicker than those found in new construction [Sullivan 1995]. Modern construction techniques are used in the the community-built school buildings that are studied in Part II of this thesis.

The ongoing Aga Kahn Housing Board/MIT Building Technology alliance concerning the thermal insulation of buildings and houses in the Northern Areas of Pakistan has the goal of appropriate technology transfer. Problems faced in any technology transfer to a developing region can be predicted by assessing the solution's degree of "appropriateness". This term encompasses the following factors:

- ◊ local availability of resources;

[1] These measurements are based on wall surface temperatures and do not include boundary layers.

◊ ability to be manufactured with local labor;
◊ congruence with traditions and social customs.

Sullivan [1995] used cellulose fibers (straw and wood matter) with wood glue to produce sample insulation boards that can be fastened to the inside of existing wall construction. His research concluded with a technique that appeared to have a cost per unit thermal resistance that was only about 10% less than expanded polystyrene. The question that remained is how can a suitable insulation product be locally manufactured from locally available materials at half of price of the expanded polystyrene?

2.1 Project Objectives

The initial effort to produce a straw-based insulation board suitable for northern Pakistan began by studying the needs and construction of the schools and houses. This revealed the need for some type of rigid insulation, as opposed to loose fill, because the buildings have single course masonry walls without an air gap. These boards should be suitable for other developing regions as well. We intended on fabricating the board from locally available waste or near waste materials, using simple machinery and requiring little energy to manufacture.

In northern Pakistan, walls have traditionally been finished with some type of plaster. Through conversations with local officials, it was summarized that the insulation material would in most cases need to be covered by a surface finish plaster. The high cost of wood in this region prohibits using wood stud and lathe work as a support system for the plaster. The board must therefore be strong enough to be installed on the interior of buildings without any wood framing and must be able to be directly and easily plastered. This plaster and board system must be able to withstand normal compressive loads without cracking or crumbling of the plaster.

2.1.1 Target Market Characteristics

We learned about the society largely through interviews during a November 1995 site survey trip to the region. We supplemented this information with assumptions based on personal experience and were then able to refine the following observations:

A) Developing economy by international standards: It is advisable to devise solutions which make use of internally produced materials and products, thus supporting the economy. It is also preferable to use low cost materials and techniques, thus increasing the chances that the proposed solution can be effectively adopted.

B) Low industrialization level: Because there currently is very little industry in the Northern Areas; it is preferable to select traditional processes that are more labor intensive than machine oriented. Indeed, if it becomes necessary to utilize new processes or techniques, they should be easy to understand to reproduce.

C) Underdeveloped transportation infrastructure: The roads in this region are not well developed and preference should be given to the use of local materials and to the possibility of distributed manufacture.

D) Tradition-oriented society: The society of the Northern Areas of Pakistan is tradition-oriented and it is important to devise a solution that blends with the traditional architecture and building practices.

2.1.2 Product Specifications

The design specifications included the following considerations:

- ◊ integrated rigid board material, i.e. not a loose fill product, that can be applied to the interior wall surface both:
  - ♦ during the initial construction of the building envelope; and
  - ♦ as a thermal retrofit to existing construction.
- ◊ it must also be strong enough that it
  - ♦ can be installed without any wood framing members or lathe;
  - ♦ accepts plaster directly; and
  - ♦ can withstand normal building loads
- ◊ thermal performance comparable to existing non-foamed insulation materials such as fiberglass batt and loose-fill cellulose
- ◊ economic viability - the cost per square foot of unit thermal resistance should be 50% or less than the cost of expanded polystyrene, the benchmark existing product in the target market
- ◊ durability and stability over time
- ◊ minimal safety risks in terms of production, material emissions and indoor air quality concerns

Having characterized the target society and defined our objectives, we began researching a variety binders for agricultural byproduct materials. We choose straw as the core material for the insulation board based on its widespread availability as an agricultural byproduct in throughout the world, including northern Pakistan.

3. Insulation Board Fabrication

3.1 Introduction

Boards have been fabricated and tested in the density range of three to 15 pounds per cubic foot (48 to 240 kilograms per cubic meter). This is a low density range with respect to structural cellulosic fiber boards which range from 20 lb/ft^3 to 45 lb/ft^3 and a relatively high range with respect to current insulation products in the US market such as polystyrene, 1 lb/ft^3. A summary of the densities, unit thermal resistances, and retail costs for current products in the US insulation market is presented in Table 3-1.

	Density lb/ft^3	Aged Thermal Resistance hr-ft^2-°F/Btu-inch	US Cost cents per R-ft^2
wood fiber insulation board	20	2.8	
fiberglass batt	1.5	3.2	1.4
cellulose wall	3.5	3.5	1.6
cellulose attic	2.2	3.6	1.0
expanded polystyrene	1.0	4.0	4.0
rigid fiberglass	5.0	4.0	10.0
extruded polystyrene	1.8	5.0	6.5
polyurethane foam	1.8	5.0	6.5
phenolic foam		7.0	6.0

Table 3-1. Densities, R-values, and costs for US insulation materials[2]

In the beginning we knew that our rigid insulation would not be able to equal the thermal performance of foams filled with a low conductivity gas, but must insulate better on a unit thermal cost basis. Typical thermal resistances for insulating materials that contain voids filled with air fall in the range of R3 to R4 per inch. We knew that R3 to R4 per inch was the probable operating range, with some possibility to go above R4 per inch, by careful control of the porous structure.

Much of our initial research focused on optimizing binder loads and exploring a variety of processes. A survey of possible methods included

1. mechanically containing the straw either in jute bags or in panels with wire and battens;
2. pulping the straw to form a board; and — hm. could be too labor intensive I need something fast!
3. utilizing a combination of adhesive binding and minor processing, such as shredding, soaking, or heating. — might be OK

The literature describes boards that have been made by all three of these methods, using wood, straw, and other materials [Suchsland and Woodson 1987; Biblis and Lee 1980;

[2] Cost data taken from listed retail prices at Home Depot, Somerville, MA, in November of 1996.

Soltes 1983; and Macdonald 1950]. Most of these products have been structural boards at high densities (30-80 pounds per cubic foot, lb/ft^3, or 480-1280 kg/m^3). The boards and panels used for insulation have had higher densities (20-30 lb/ft^3 or 160-480 kg/m^3) and R values in the R2 to R3 per inch range. This is substantially lower than the R4 to R7 per inch range of the boards that dominate today's market for rigid insulation. The 20 lb/ft^3 density board results in structural performance well beyond the requirements of a rigid insulation material. In addition to diminishing thermal qualities, the higher densities require too much straw to meet the cost criterion for the target market of northern Pakistan.

Previous work at MIT had shown that it was indeed possible to achieve R3 per inch with straw boards of 2.4 lb/ft^3 density [Sullivan 1995]. This technique used polyvinyl acetate (PVA or white paper glue) as a binder for cut straw of fiber length less than one inch. The binder load was 39% of total mass of the board. An economic analysis for the target market showed this board to have relatively little economic benefit in comparison to existing product benchmark, rigid expanded polystyrene board. Using this research as a starting point, our initial goals were to lower the percentage cost of the binder, either by decreasing the PVA density or by utilizing a different binder altogether, and to increase the R-value per inch. R4 per inch appears to be the limit for insulation materials that are not based on closed cell foams. We chose R3.5 per inch as the threshold performance for our product with the hope of achieving R4.

In the adhesive binding category PVA, starch in the form of wheat flour, sodium silicate (water glass), and polymeric methylene diphenyl diisocyanate (polymeric MDI) were tried as adhesives using both uncut and shredded straw. Various methods of application were investigated such as spraying, foaming, and dipping, at various loading rates, with and without wetting agents. Details of the exploratory board research are presented in Chapter 5. Some crude initial experiments indicated that R3 per inch could be achieved at double the density of the Sullivan's [1995] work, although these results appear to be in error based on a review of the thermal analysis. We had speculated that six lb/ft^3 might be the upper density limit for thermal resistance values above R3 per inch. A later pilot study into the interplay of fiber length, density, and thermal resistance hinted that the R-value might continue increasing up to eight lb/ft^3 before beginning to diminish.[3] The results of this study are summarized in Figure 3-1. This was the first indication that a 12 lb/ft^3 board might be able to achieve R3 per inch.

[3] The initial indication of this trend came from an MIT undergraduate building technology class experiment for which I was the teaching assistant. The thermal results of that study are not statistically significant because only one board was produced at any given density, fiber length concentration profile, and binder load. The board making process was also not controlled across the samples. Despite these limitations, this trend was confirmed in the isocyanate experiments detailed in the Chapter 4.

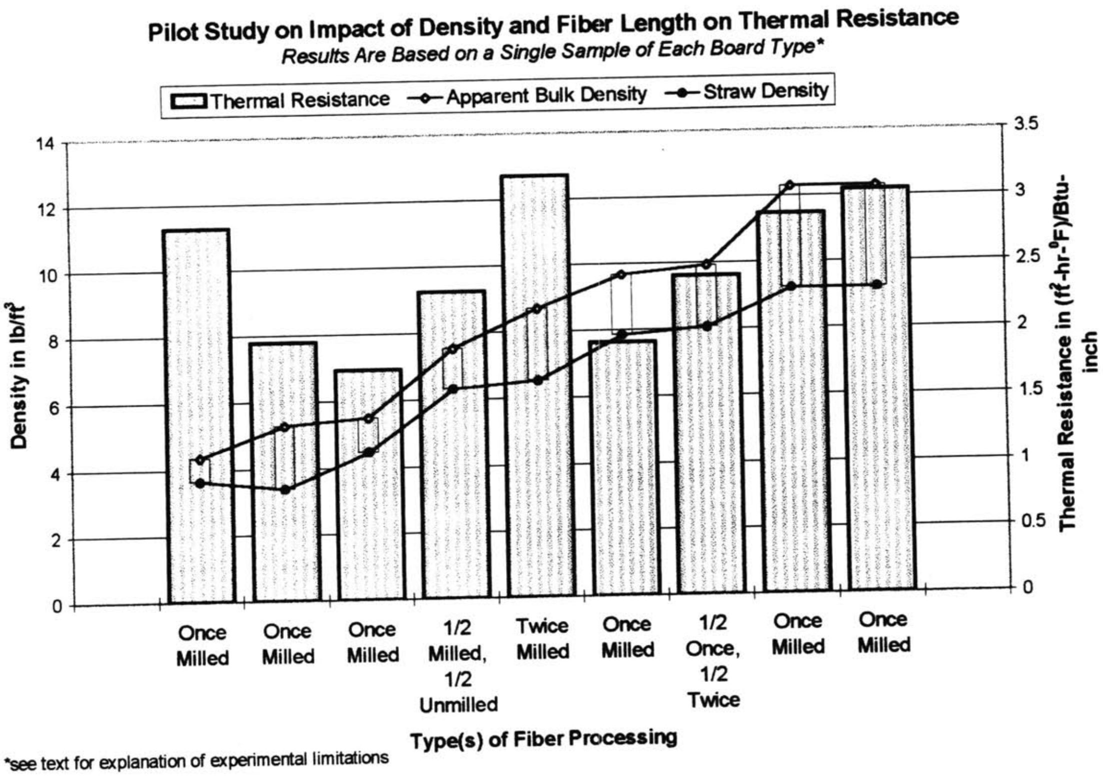

Figure 3-1. Pilot Study on Impact of Density and Fiber Length on Thermal Resistance

The significant advantage from higher density is better structural performance at decreased binder loads, although this result was not demonstrated in the pilot study.[4] We believe the increased structural performance at higher densities is related to the increased fiber to fiber contact area. The thought is that the fibers have greater surface area for weak hydrogen bonding as well as increased contact sites for mechanical, fiber to fiber, inter-weaving bonds.

To efficiently experiment with methods of reducing the binder load, small samples of eight inches square and one inch thick were formed in the five lb/ft^3 to six lb/ft^3 density range. The smaller samples were qualitatively and rather crudely compared on structural and economic properties. The results of the comparisons were used to guide the next iteration of investigation. For the economic analysis, a nominal thermal resistance value of R3 per inch was assumed for all the panels. Material prices in northern Pakistan were collected with the assistance of the Aga Khan Housing Board for Pakistan. The results suggested that structurally sound boards could be made using either PVA, sodium silicate or wheat flour. From an economic perspective however, only wheat flour could compete with existing insulation boards. It is possible the other binders could be used more effectively with the addition of heat to the process. We had chosen to avoid adding heat because of

[4] Binder load here refers to the percentage of the total mass of the board. Correspondingly, this is also the percentage contribution to the board's apparent bulk density.

the limited fuel resources in the target market of northern Pakistan. Polymeric MDI was not used in the initial experiments due to ventilation limitations of our experimental facility. However, estimations of the economic costs of straw-MDI boards were made to determine whether the binder was worth pursuing.

3.1.1 Preliminary Economic Considerations

A preliminary effort at comparing the cost of various options is presented in Figure 3-2. These results are highly theoretical because the thermal resistance values for all the samples are assumed to be R3 per inch. The horizontal cost bars are shown for boards made with different binders and different binder loading as a percentage of the total board mass. The alternative binders were PVA (polyvinyl acetate), sodium silicate, wheat flour, sodium hydroxide, and isocyanate. The sodium hydroxide is used to pulp the straw and is not really an adhesive (refer to Section 5.3 for more information on this process). For the water soluble binders: PVA, sodium hydroxide, sodium silicate, and wheat flour, the bars represent the material costs of the best sample boards we had made by June of 1996. The expanded polystyrene is noted by an asterisk because the cost shown is the wholesale price of the finished product in northern Pakistan rather than just the material burden. The cost of fabricating the straw panels is assumed to be relatively small due to the low cost of local labor. More detailed and thorough economic analyses are presented in Sections 4.3, 7.3, and 10.1. At the time of this preliminary analysis, we had not fabricated any boards using isocyanate (MDI) so we made cost estimations at three different binder loads: two percent, 10%, and 20% of the total mass of the board.

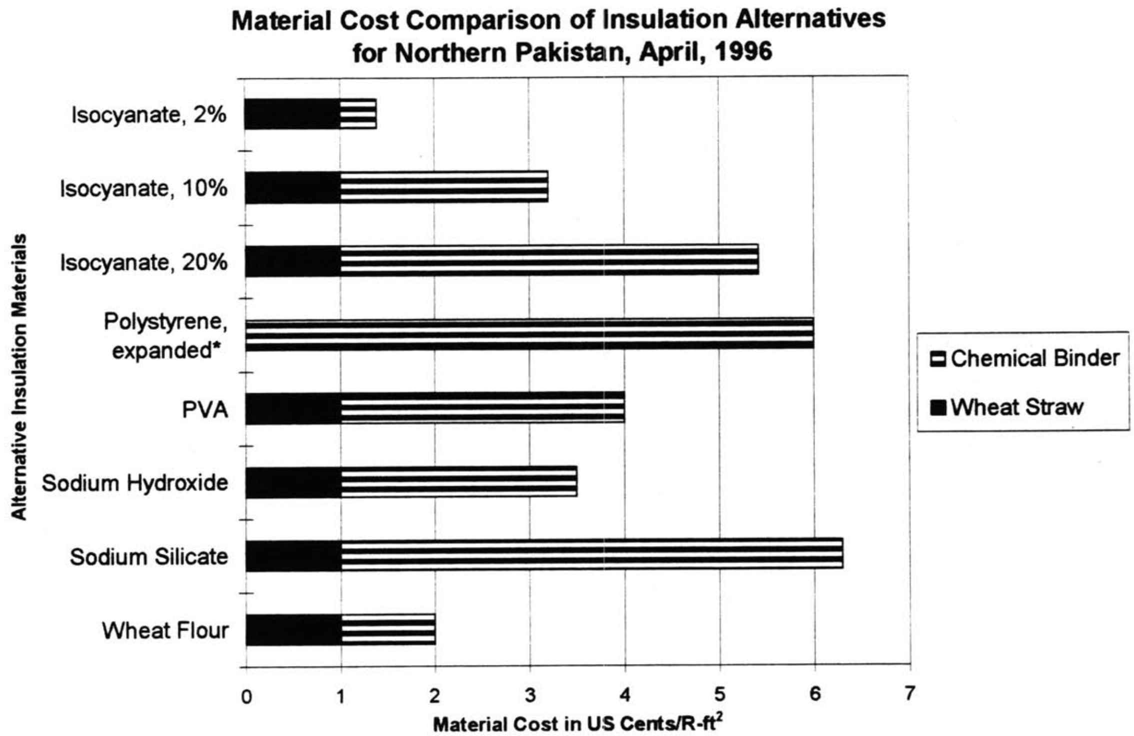

Figure 3-2. Cost comparison of alternative insulation materials researched at MIT

The graph shows that for the boards made with water based binders, we were beginning to drive the materials cost below that of the locally available rigid insulation, expanded polystyrene. In the case of isocyanate, we predicted that we would be able to make an economically viable board at resin levels below 10%. Although 10% is a relatively large mass fraction for a high performance resin, the graph shows that this panel would still be 53% of the delivered material cost for expanded polystyrene. Overall isocyanate was an extremely attractive prospect for further research.

Samples bound with wheat flour are estimated to cost approximately 67% of the expanded polystyrene benchmark. The problem with the straw-wheat flour combination is that it is so nutrient rich that most species of life could consume it quite easily. A truly sustainable model would be to store surplus agricultural biomass in the form of rigid insulation boards. When the natural conditions did not provide sufficient feedstocks for the livestock, one can imagine removing the insulation from the buildings and feeding it to the livestock. Officials from the region informed us that the people wanted modern materials and did not to be treated as primitives. This is one of the reasons we abandoned further research in this direction. Adding preservatives and pesticides to mitigate the risk of bioattack remains an option, however this research was not completed due to time constraints, a lack of appropriate test facilities, and the promise of MDI.

Polymeric MDI[5] is a high performance binder that is a normal component of polyurethane. It is marketed as an ecological binder because it does not contain formaldehyde and after it has cured, it does not result in any off-gassing of toxic compounds. In this experiment we used the heat-curing version, although a formulation of the product exists which cures at air temperature.[6]

3.2 Experimental Design

3.2.1 Hypothesis

It is our belief that lower densities of cellulosic materials provide better thermal performance but poorer structural characteristics. We hypothesize that at a given density of cellulosic material, a furnish[7] with a higher percentage of fines will result in improved thermal resistance and decreased structural performance. We hypothesize that there exists an optimal formula for a low density, low-cost, cellulosic, rigid insulation board involving percentage binder load, furnish size concentration profiles, and density.

3.2.2 Objective

To fabricate and test the thermal and structural properties of wheat straw insulation boards using polymeric MDI as the binder. The experimental variables are density, binder load, and fiber size concentrations.

3.2.3 Description of Experiment

Our initial assumption was that we would test two percent, five percent, eight percent, and 11% binder load by mass fraction. These numbers were refined based upon the results from the first and second blender loads. For each blender load, we fabricated boards of one or two different densities. The densities originally intended to be tested were two lb/ft^3, four lb/ft^3, six lb/ft^3, eight lb/ft^3, and 10 lb/ft^3. However the settled density of the binder-covered furnish was approximately six lb/ft^3. The fabrication process, which will be described later in this chapter, is limited to producing boards above the settled density of the raw material. Ultimately boards were made over a density range of six lb/ft^3 to 15 lb/ft^3 and a binder loading range of one percent to 11% by mass.

The impact of particle size concentration was studied by making boards from furnish of two different fiber length concentration profiles. To control for errors introduced in the fabrication process, three boards were produced at each specified density, binder load, and particle size profile. This protocol was modified to accommodate the "surplus" furnish from a blender load at a given binder concentration. In this case, enough material was left

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[5] The chemical name for polymeric MDI is Polymeric 4,4'-Diphenylmethane Diisocyanate. The specific product we used is Rubinate™ 1840. Rubinate is a trademark of ICI Americas Incorporated.

[6] The heat-curing formulation is 100% Polymeric MDI. The air temperature curing version is 90% Polymeric MDI and 1-5% Modified Polymeric MDI.

[7] The term *furnish* is used to describe both the raw milled straw and the binder-covered straw material before the binder has cured.

to make one high density board (12 to 15 lb/ft^3) or two boards at low density (six to seven lb/ft^3) but not enough existed to make a complete set of three.

We had originally intended to test the contribution of the fabrication process to the board performance by replicating some runs with an alternate binder such as PVA or sodium silicate. This would have allowed us to compare the structural and thermal efficacy of the isocyanate independent of the fabrication process. Unfortunately we ran out of time on the equipment before these runs could be performed.

3.2.4 Experimental Method

The process used for board fabrication has four stages:

1. preparation of the furnish with a hammer mill and vibrating screen separator;
2. spray application of the binder in a ventilated tumbling drum;
3. careful sifting of the furnish into mold form; and
4. curing of the binder through a heated cycle in a hydraulic press.

3.2.4.1 Furnish Preparation

Wheat straw was supplied to ICI by Prime Board Inc. for the experiment. The preparation of the furnish with a hammer mill leads to material composed of a variety of fiber lengths and widths. The furnish properties depend on the type of hammer mill used. It is possible to characterize the furnish by separating the fibers using screens of varying gap dimensions. For this study, the furnish is characterized using 1/4 inch, 1/8 inch, and 1/32 inch screen sizes. The screens are shaken so that a separation into three groups occurred based on size. Once the straw has been through the hammer mill, the thickness dimension for the *fines* and *medium* fibers becomes negligible relative to the fiber width and length. With the *large* fibers, the cylindrical body of the straw stalk may still be intact and therefore the maximum width and the maximum height are equal to the stalk diameter. For these reasons the furnish has been characterized by length and width only. The three fiber groups describing the size profiles of the experimental furnish are summarized in Table 3-2.

Qualitative Name	Average Length mm	Average Width mm
fines	5	1
medium	10	2
large	19	3

Table 3-2. Furnish fiber size characteristics

The output from the hammer mill used in this experiment is composed of approximately 33% fines, 58% medium fibers, and eight percent large fibers by weight according to the criteria shown in Table 3-2 and is referred to hereafter as *unscreened* furnish. To study the impact of the fiber length concentrations, some of the output from the hammer mill was separated with a four millimeter vibrating screen apparatus. This output is composed of approximately 12% fines, 79% medium fibers, and nine percent large fibers and is referred to hereafter as *screened* furnish. It appears as though the vibrating screen may have broken down 15% of the large fibers, thereby generating a disproportionate increase in the percentage of medium fibers.

It was the intention of the experiment to approximate the fiber size concentration profile of the wheat straw furnish from the hammer mills in northern Pakistan. During the site survey trip, we collected a sample which the local people asserted was typical of the milled wheat straw furnish. This sample was composed of 27% fines, 38% medium fibers, and 35% large fibers. A summary of these compositions is given in Table 3-3. A picture of the fiber group concentrations for the three furnish types is shown in Figure 3-4. For this picture, one gram of each type of furnish has been separated into the fines, medium fibers, and large fibers (top to bottom).

Furnish Type	Fines	Medium Fibers	Large Fibers
Pakistani Sample	27%	38%	35%
Unscreened	33%	58%	8%
Screened	12%	79%	9%

Table 3-3. Fiber concentration profiles

3.2.4.2 Application of the Binder

A four foot diameter blender with exhaust ventilation was used to apply the MDI to the straw. The round tumbling chamber is approximately 18 inches wide so that the blender appearance is similar to that of a vertical, cylindrical pancake (Figure 3-3). The circumference is lined by 10 inch high mixing baffles running width-wise and spaced every 18 inches around the circumference of the blender. External rollers support the chamber and a motor imparts the force to spin the chamber. The baffles in conjunction with the centrifugal force from the spinning motion carry the furnish up and around the circular tumbler path. Near the top, gravity takes over and the furnish falls back to the bottom. As the furnish falls it is covered by a thin layer of binder. The MDI is applied through three atomizing spray heads of the type used with paints. More robust blender models avoid paint type spray guns by utilizing a spinning cone type of sprayer. In this device the polymer is fed to a spinning cone trough several feed tubes. The cone has an external housing separated by a small air gap. The air gap acts as a nozzle to direct the spray. As droplets of polymer hit the spinning cone they spread out, gain velocity, and fly out through the nozzle. This device is less susceptible to clogging than paint type spray guns.

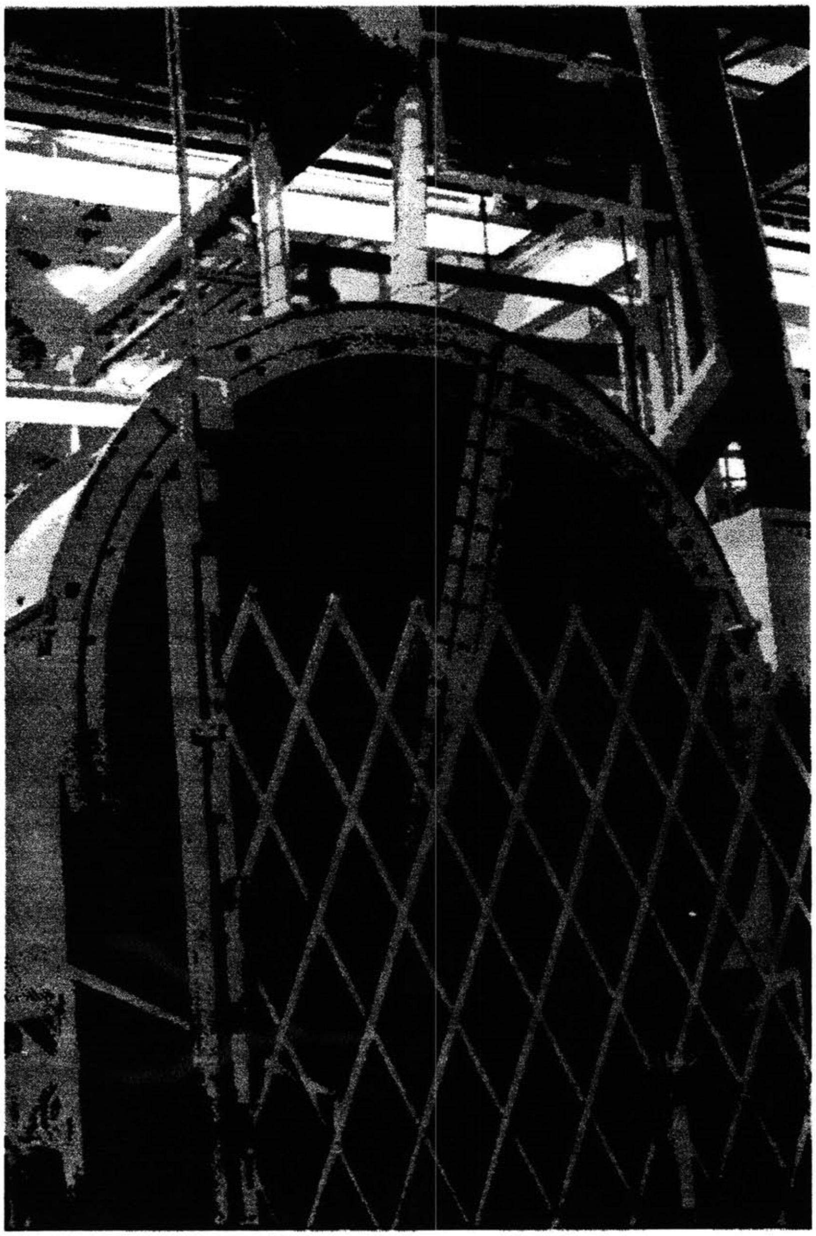


Figure 3-3. Body of a binder blender used for non-production runs (behind grate)

Figure 3-4. Fiber size concentration profiles for Pakistani, unscreened and screened wheat straw furnish (l to r), 1 gram samples, scale in inches

Forming the Board

The furnish was then sifted by hand into a four-sided wooden form. The form sits on top of a metal platen that is used to transport the board until it has been pressed and cured. The platen is at room temperature and is covered with a mold release agent. The release agent prevents the binder from bonding with the metal surface. The sifting was performed carefully to make sure the boards were homogenous in all dimensions. If large air pockets existed at this stage, the final product would be non-uniform and have weak spots.

Pressing the Board and Curing the Binder

The form is removed and the platen is placed inside of the heated hydraulic press. The press is lowered until it hits one inch steel spacers. The top platen is heated to 370 °F for seven minutes. This formula has not been optimized but was selected because it was known to work. For thicker boards it may be necessary to heat both the top and the bottom platens to make sure the center of the board is heated sufficiently for curing of the binder.

The major constraints on the board fabrication aspect of the experiment were the blender load capacity and the amount of time allowed on the equipment. The fabrication process lasted 1 1/2 days. Each blender load could accommodate fifteen pounds of furnish. The blender was run until all of the specified binder had been applied. This generally required about ten minutes to complete. The boards we made had of dimensions 28" x 18" x 1" ($l * w * h$). This resulted in four to six boards per load. A total of forty-one boards were produced.

3.2.4.3 Testing Method

The boards were all tested for thermal and structural properties using the following three tests

1. Thermal conductivity
2. Compression resistance to a range of loads
3. Bending resistance to a range of loads and stress at rupture

4. Thermal, Structural, and Economic Results with MDI

This chapter summarizes the results of thermal and structural tests and then reviews the economic analysis to select optimal board properties.

1. The first section describes the thermal performance of these boards.
2. The second section describes the results of the structural testing.
3. The third section covers the economics of board selection.

4.1 Thermal Performance of Straw Insulation Boards

4.1.1 Overview of the Thermal Conductivity Tester

The equipment used to measure the thermal properties of the of the boards is an unguarded flat screen thermal conductivity tester. An exploded diagram of the tester is shown in Figure 4-1. During a test, the experimental and control samples are pressed against each other and the screen, sandwiched between the cooling plates. This device is referred to as unguarded because the temperatures along the edges and the top and bottom surfaces are not controlled. A detail of the nichrome screen heater is shown in Figure 4-2. The screen mesh has 40 wires per linear inch in both the width and length directions.

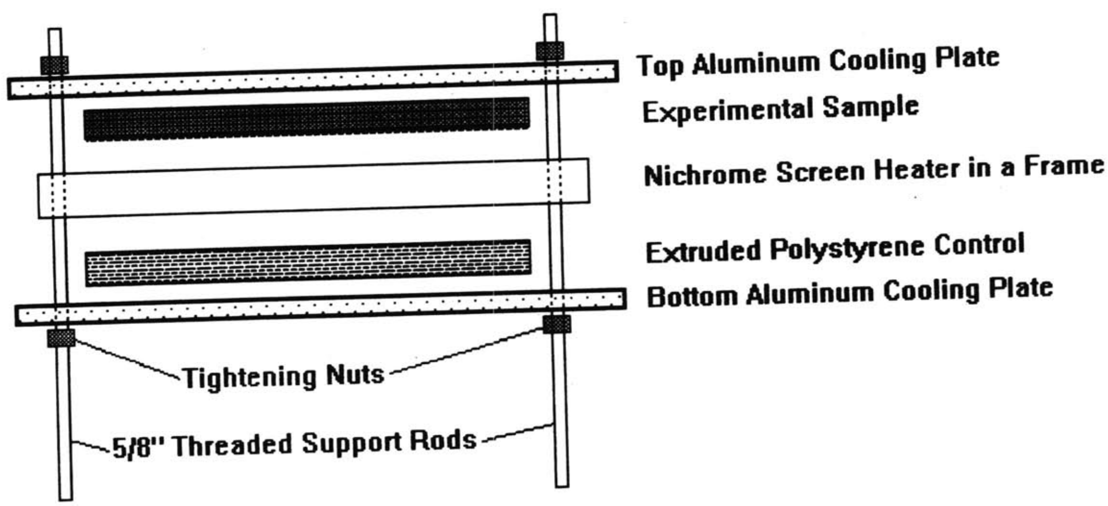


Figure 4-1. Exploded view of the flat screen thermal conductivity tester

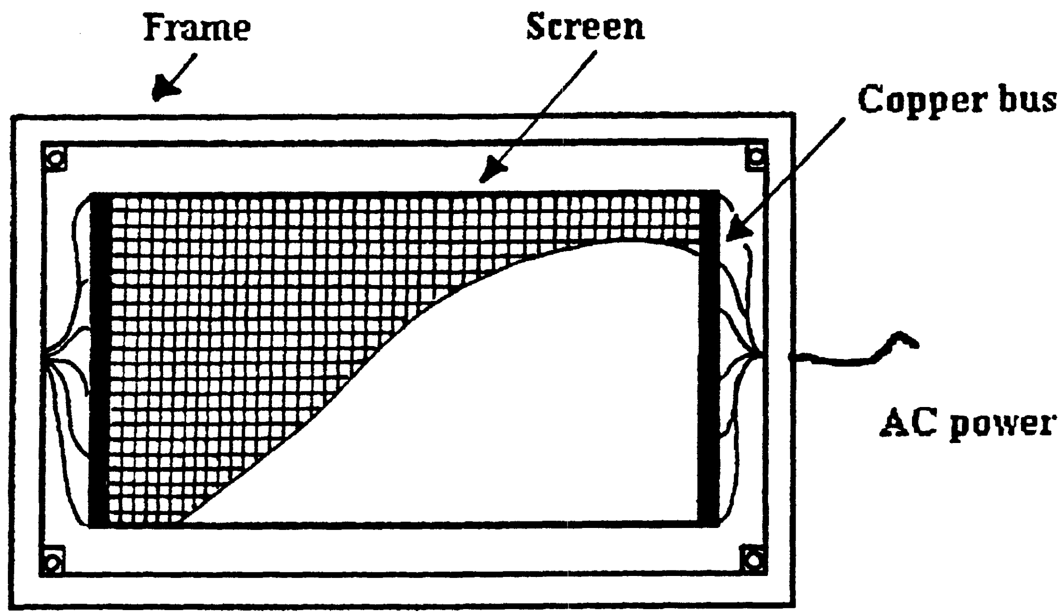


Figure 4-2. Flat screen heater assembly [Sullivan 1995]

The goal for this type of tester is to approximate one dimensional heat flow. For this reason the sample thickness should be much smaller than the width and length dimensions. This particular conductivity apparatus has a sample surface area requirement of 25 inches by 15 inches which accommodates sample up to 1.5 inches thick [Sullivan 1995].

During a test, the edges around the sample boards is insulated with fiberglass batt insulation to guard against lateral heat flow near the edges. The temperature of the top plate, screen, and bottom plates are measured with a network of 39 chromega-constantin thermocouples. The thermocouples are evenly spaced every two inches in a cross pattern as shown in Figure 4-3. This pattern is used on interior sides of the top and bottom plates and on the screen. Another thermocouple of the same type is used to monitor the ambient temperature surrounding the test apparatus during the measurements. The thermocouples were calibrated using a glass mercury thermometer, boiling water and an ice bath. All of the thermocouples were within ±0.5 °F of each other and within ±1.0 °F of the mercury thermometer.

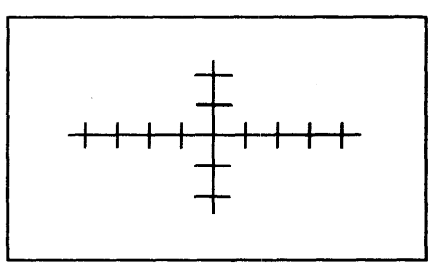


Figure 4-3. Thermocouples are placed at the cross marks, spaced every two inches

The tests can be run either with experimental samples on both the top and the bottom (double sided test) or with the sample on the top and a calibrated control on the bottom (single sided test). The double-sided test is more accurate but the single-sided test is much easier to execute. All tests presented here have been one-sided tests using a sample of extruded polystyrene from U.C. Industries of Tallmadge Ohio. This control sample has a calibrated thermal resistance of R5.2 ± two percent. The idea behind this test is that if the thermal resistance (*l/k*) of the control sample, the area, and the temperature difference across the sample are all known, then one can easily calculate the heat flow through the bottom sample using Fourier's law of steady state, one-dimensional heat conduction:

$$Q = A * (k/l)(T_{hot} - T_{cold})$$

where

Q	=	heat flow, Btu/hr
A	=	surface area of the sample, ft^2
k	=	thermal conductivity of the material, Btu/hr-ft2-°F
l	=	thickness of the material in the direction of heat flow, ft
T_{hot}	=	temperature of the material surface next to the nichrome heater, °F
T_{cold}	=	temperature of the material surface next to the ambient condition,°F

Using the screen resistance and the voltage drop across the screen, one can determine the total heat flow through screen. Subtracting the heat flow through the bottom sample from the total heat flow leaves the heat flow through the top experimental sample. Then using the temperature difference across the top sample, the heat flow through the top sample, and the sample area and thickness, the thermal conductivity of the thermal conductivity of the experimental sample is easily calculated.

Detailed descriptions of the calibration of our unguarded flat screen thermal conductivity test apparatus can be found in other works [Sullivan 1995; Harvey 1997]. Sullivan's [1995] error analysis suggests an overall accuracy of ± seven percent on the tester and more recently Harvey's [1997] analysis points to an accuracy of ± five percent. Three tests runs were performed on several samples and the standard deviation among these sets was 0.05 which correlates to 1% of the measured value. This suggests that the results show better repeatability than they do absolute accuracy.

Mr. Harvey and I made three significant improvements to the accuracy of the system in preparation for testing the straw-MDI boards. The first was to carefully measure the electrical resistance of the nichrome screen heater under both room temperature and test conditions. Unlike most metals, the resistance of nichrome changes very little with temperature. By doing this we were able to eliminate the error associated with the clamp-around, magnetic field ammeter we had previously been using to measure current. The scale of the ammeter that we had been using gave readings accurate to 0.5 amps in our range of measurement. We can now take a single voltage reading across the screen from which the current and Joule (I^2R) heating can be calculated. The voltage meter displays to a tenth of a milliVolt in our range of interest. With this technique, we believe the current measurements are accurate to a milliAmpere.

A second improvement was to take seven thickness readings per panel using a calibrated dial gauge. The readings were taken three inches in from the edges and in the center of the board. Previously we had taken thickness measurements using calipers limited by a two inch throat. The average thickness of the panel is extremely important to all of the thermal and structural calculations.

The third alteration was to apply light pressure to the top plate using bolts with washers. Although the nichrome screen heater is held in tension by the frame, small ripples across continue to exist along the length of the screen. These ripples could cause unwanted air voids to exist between the samples and the heater. Applying light pressure compresses the screen between the experimental and the control samples, ensuring a low contact resistance on each side. We hand tightened the bolts, being careful to only compress the screen and not the samples. An improvement on this technique would be to use a torque wrench to ensure the panels were not being compressed and to control for compression of the screen across the test runs.

The tests were performed in an environment where the ambient temperature that ranged between 68 °F and 72 °F. The screen heater temperatures averaged between 92 °F and 97 °F and the mean top plate temperature was approximately 75 °F. Therefore the mean temperature difference across the experimental panels was approximately 20 °F and the mean bulk temperature of the measurements was approximately 80 °F. Each test was run for a minimum of five hours to allow the heat flow to achieve steady state conditions.

4.1.2 Effect of the Furnish's Fiber Size Profile on the Thermal Resistance

4.1.2.1 Board Properties with Binder

Nearly identical sets of samples were produced with two percent binder loading at eight lb/ft^3 and 10 lb/ft^3. The results of the these tests are presented in Figure 4-4 and Figure 4-5. At eight lb/ft^3, there is a two percent average increase in the thermal resistance of boards made with unscreened furnish over those from the screened furnish. At 10 lb/ft^3, there is a four percent average increase shown by the boards made with unscreened furnish. The thermal resistance's of all of the eight lb/ft^3 boards are significantly higher than those of the 10 lb/ft^3 boards. Despite the fact that these percentage change are below the ± five percent accuracy of the test apparatus, they are significant results. The repeatability of the tests is very high (within 1%) and hence relative comparisons below 5% differences should not be discounted.

The fact that the relative impact of the fiber size concentrations is larger at the 10 lb/ft^3 is probably due to a composite structure that optimizes the average size of the air gaps or voids. Convective heat transfer through air is much more efficient than heat conduction through air. The optimal void volume for an insulating material occurs when heat is transferred by conduction through the air voids rather than by convection. At 10 lb/ft^3, the mean void size in the screened boards is probably smaller than that of the unscreened boards. The unscreened boards contain 21% more fines than the screened boards (see Table 3-3 in Section 3.2.4.1). The settled density of the fines is higher than the settled densities of the medium and large fibers. This suggests that the medium and large fibers in an unscreened 10 lb/ft^3 board are less compressed than the medium and large fibers in the screened boards at 10 lb/ft^3.

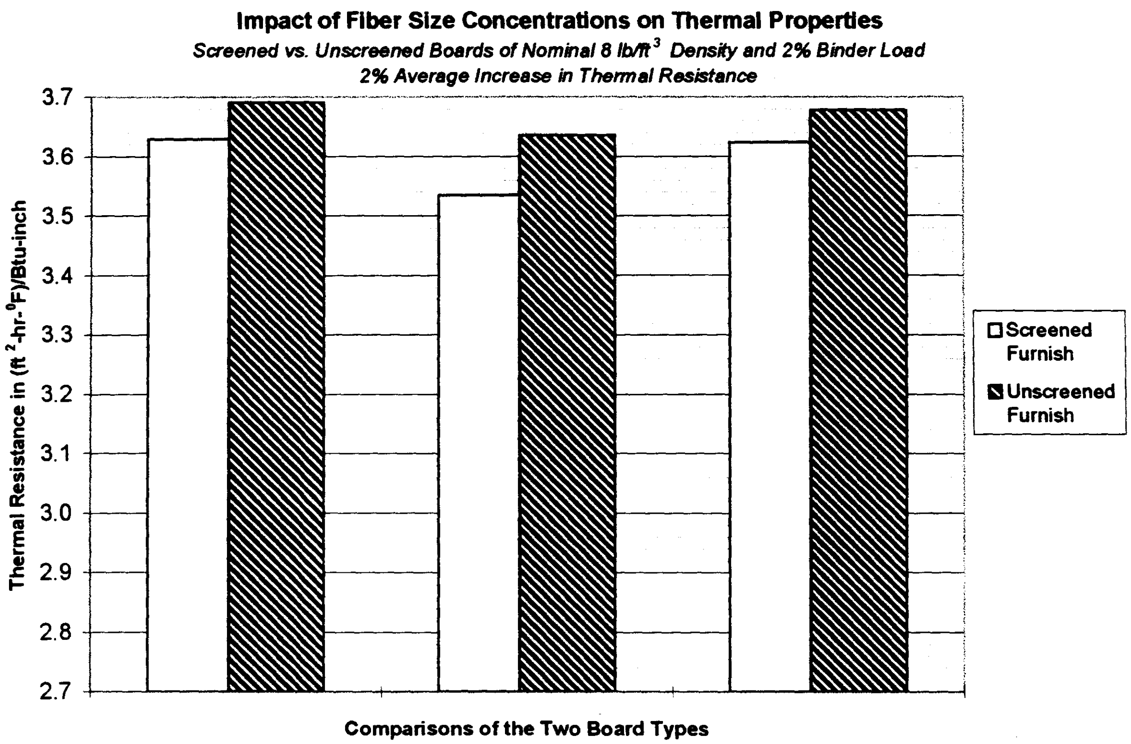


Figure 4-4. Thermal impact of fiber size concentrations at 8 lb/ft^3 and 2% binder load

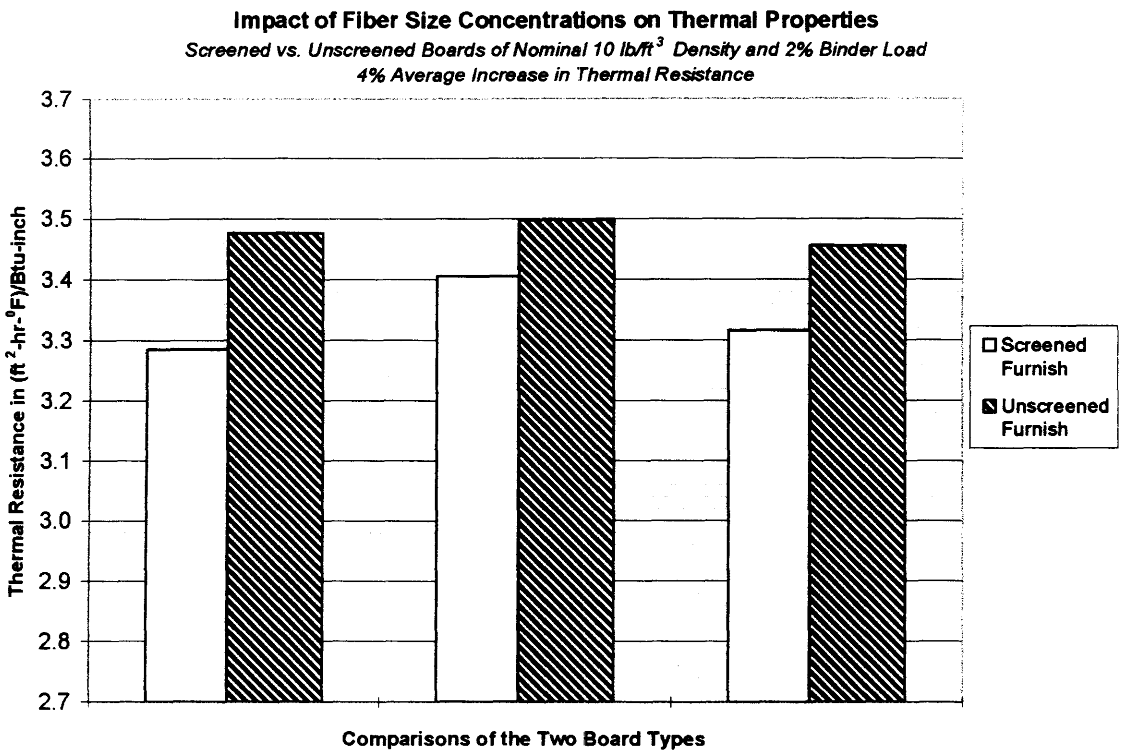


Figure 4-5. Thermal impact of fiber size concentrations at 8 lb/ft³ and 2% binder load

This trend may reverses at higher densities. At 12 lb/ft³, the thermal resistance of the screened sample is one percent higher than the unscreened sample. At 15 lb/ft³, the thermal resistance of the screened sample is three percent higher than the unscreened sample. These results are presented in Figure 4-6. It should be noted that only one board of each type shown in Figure 4-6 was fabricated. Therefore this information is provided as an avenue for further investigation. It appears that above the optimal density for unscreened furnish, the larger percentage of fines imparts higher thermal conductivity. It could be this result stems from increased surface contact area for heat conduction between the fibers. The interplay of the board's fiber size profile and its density is depicted in Figure 4-7.

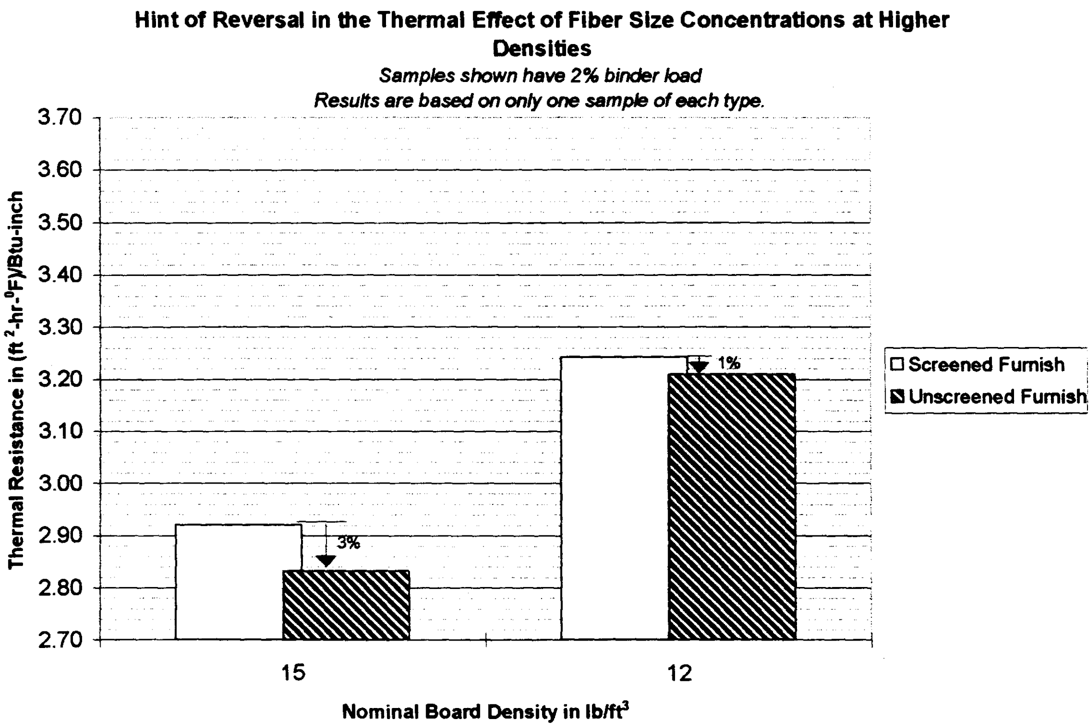


Figure 4-6. Apparent reversal of thermal impact at higher densities.

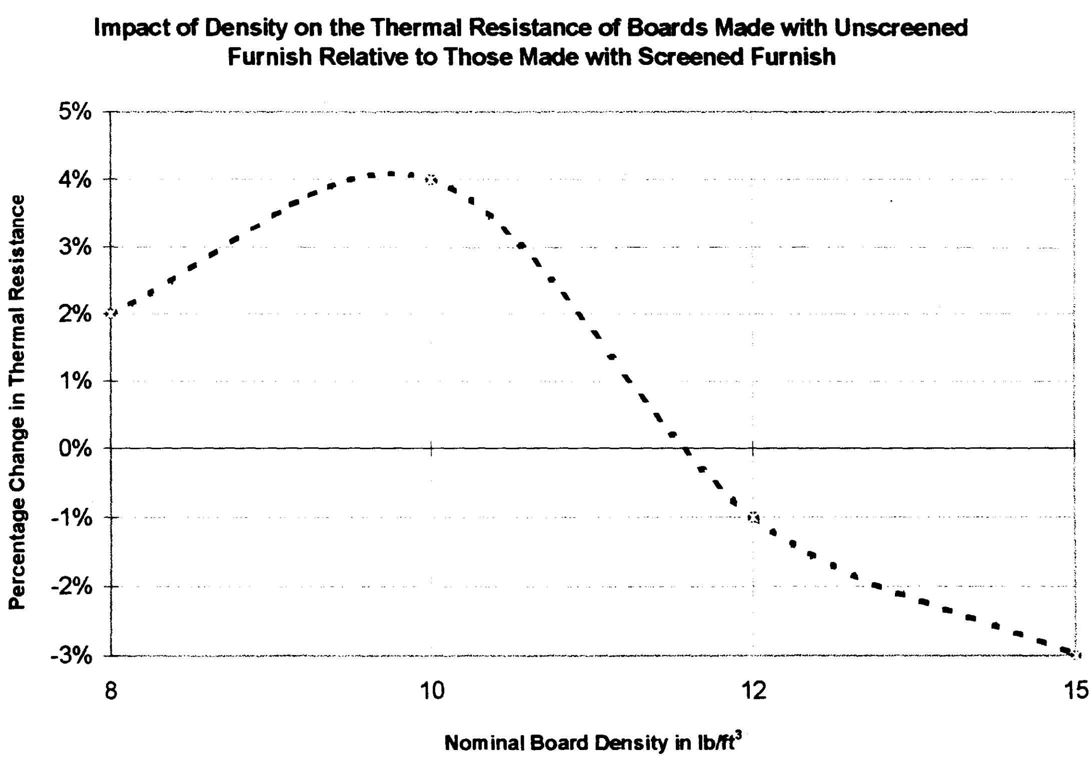


Figure 4-7. Interplay of density and the board's fiber size profile.

4.1.2.2 Furnish Properties without Binder: sub-experiment with a different furnish type

For this sub-experiment, screened, unscreened, and fines were separately placed as loose fill in the thermal conductivity tester. It is important to note that the furnish used in this sub-experiment was made with oat straw and a yard waste mulcher in place of a hammer mill. The furnish properties include medium and large fiber groups that are greater in size than the comparable furnish groups in the main experiment. For these reasons the results should not be directly compared with the wheat straw board results of the main experiment. The thickness was controlled to one inch using extruded polystyrene spacer strips around the edge of the plate. The density was 5.4 lb/ft^3 for both the screened and unscreened furnish. However we were unable to achieve this density with the fines because its settled density was closer to 5.9 lb/ft^3. The results of these tests are presented in Figure 4-8.

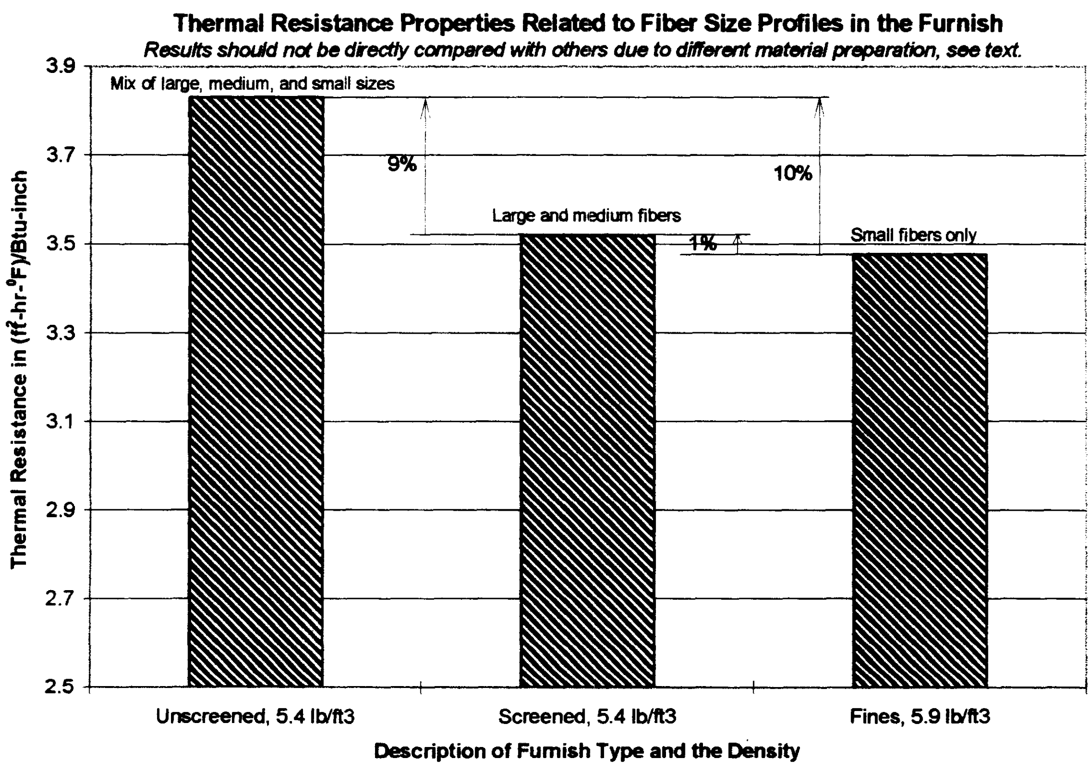


Figure 4-8. Impact of fiber size profile on the thermal resistance of the furnish

This is an oat straw furnish that was prepared with a yard mulcher

The one percent difference between the thermal resistance of the screened material and that of the fines may be an artifact from the slightly higher tested density of the fines. Both of these furnishes show about a 9% reduction in thermal resistance from that of the unscreened material. We had anticipated that the fines would have the best thermal resistance due to smaller average inter-particle air spaces. The results suggest that the mix of fiber sizes found in the post-mill unscreened furnish produce the optimal thermal properties.

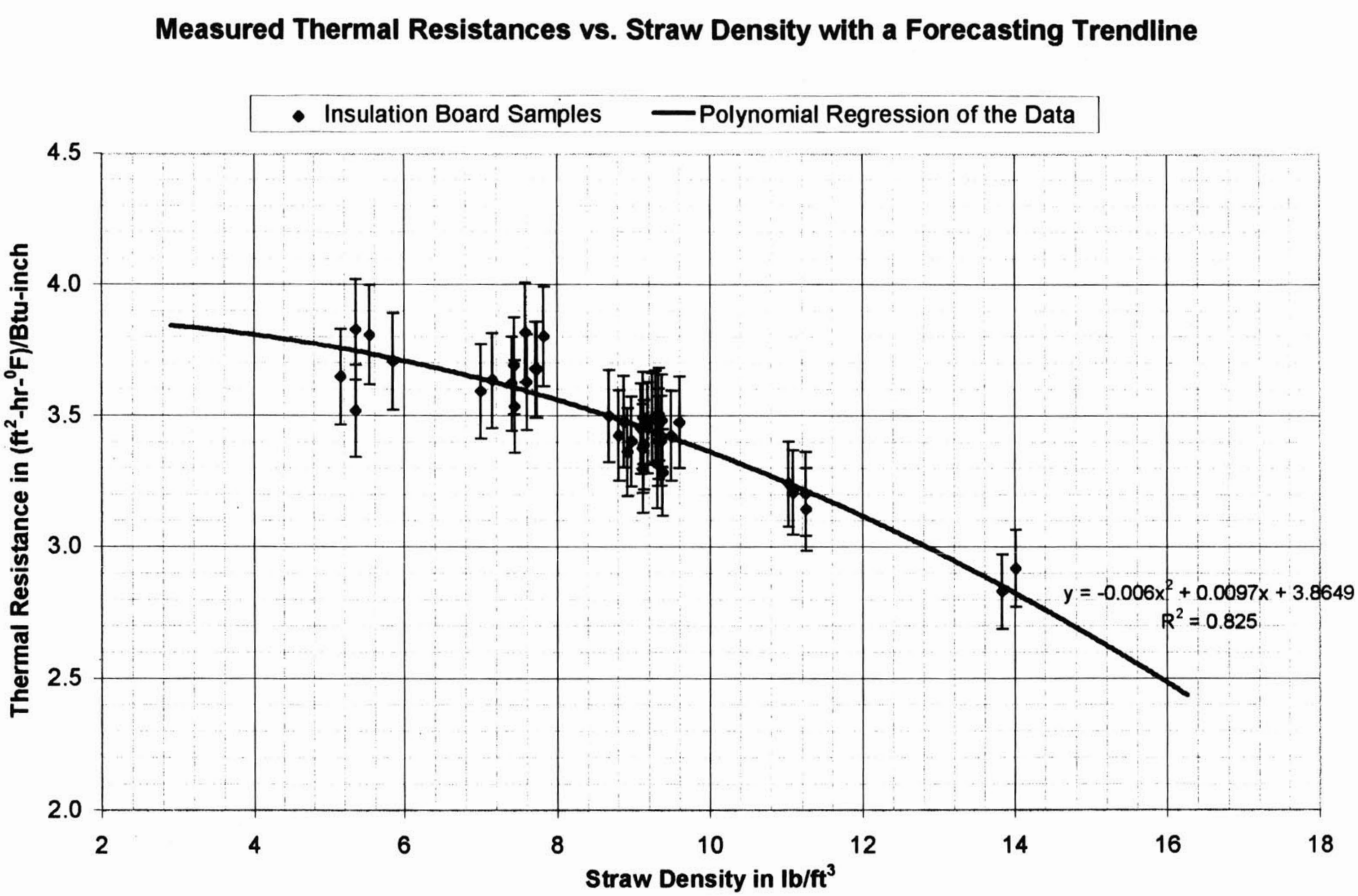
4.1.3 Effect of Straw Density on the Thermal Resistance

The impact of the straw density on thermal resistance is significant. The results are summarized in Figure 4-9. Boards with straw densities falling around the 5.7 lb/ft^3 mark showed the best thermal resistance values. These values were closely matched by some of the boards around 7.8 lb/ft^3 straw density. A second order polynomial regression of the data is shown with a forecast for several densities above and below the experimental range; no conclusions can be drawn as to the accuracy of the projected data without more testing. Accuracy error bars are shown for +/- five percent, however the proximity of the points to the trendline suggests good repeatability across the sample sets.

A comparison of the thermal resistance with both the bulk density and the straw density is presented in Figure 4-10. Abrupt changes in density are mimicked by abrupt changes in thermal resistance. The delta between the bulk density and the straw density, shown on the graph as vertical bars between the two density plots, is created by the binder load. There is no apparent relation between this delta and the thermal resistance.

4.1.4 Effect of the Binder Load on the Thermal Resistance

The effect of the binder load was studied at the 10 lb/ft^3 bulk density using binder loads of 11%, eight percent, six percent, four percent, two percent, and one percent. At the eight lb/ft^3 bulk density, binder loads of eight percent, six percent, four percent, and two percent were studied. The thermal resistance values for these boards are presented in Figure 4-11 and Figure 4-12. The thermal resistance values are not affected by the binder load in the range studied here.



*Note: The error bars on the measured resistance values are +/- 5%.

Figure 4-9. Impact of density on thermal properties

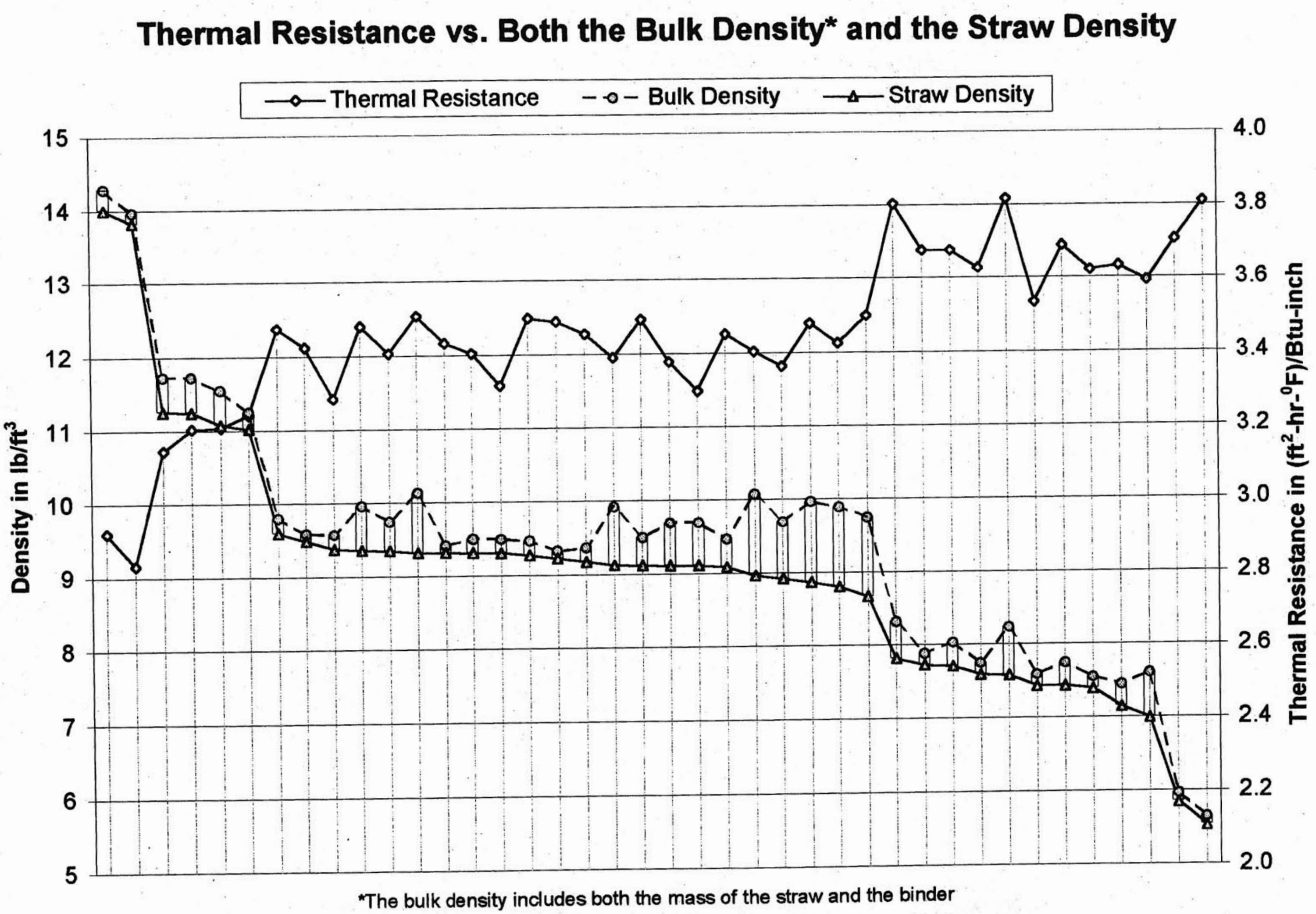


Figure 4-10. Thermal resistance vs. both the bulk density and the straw density

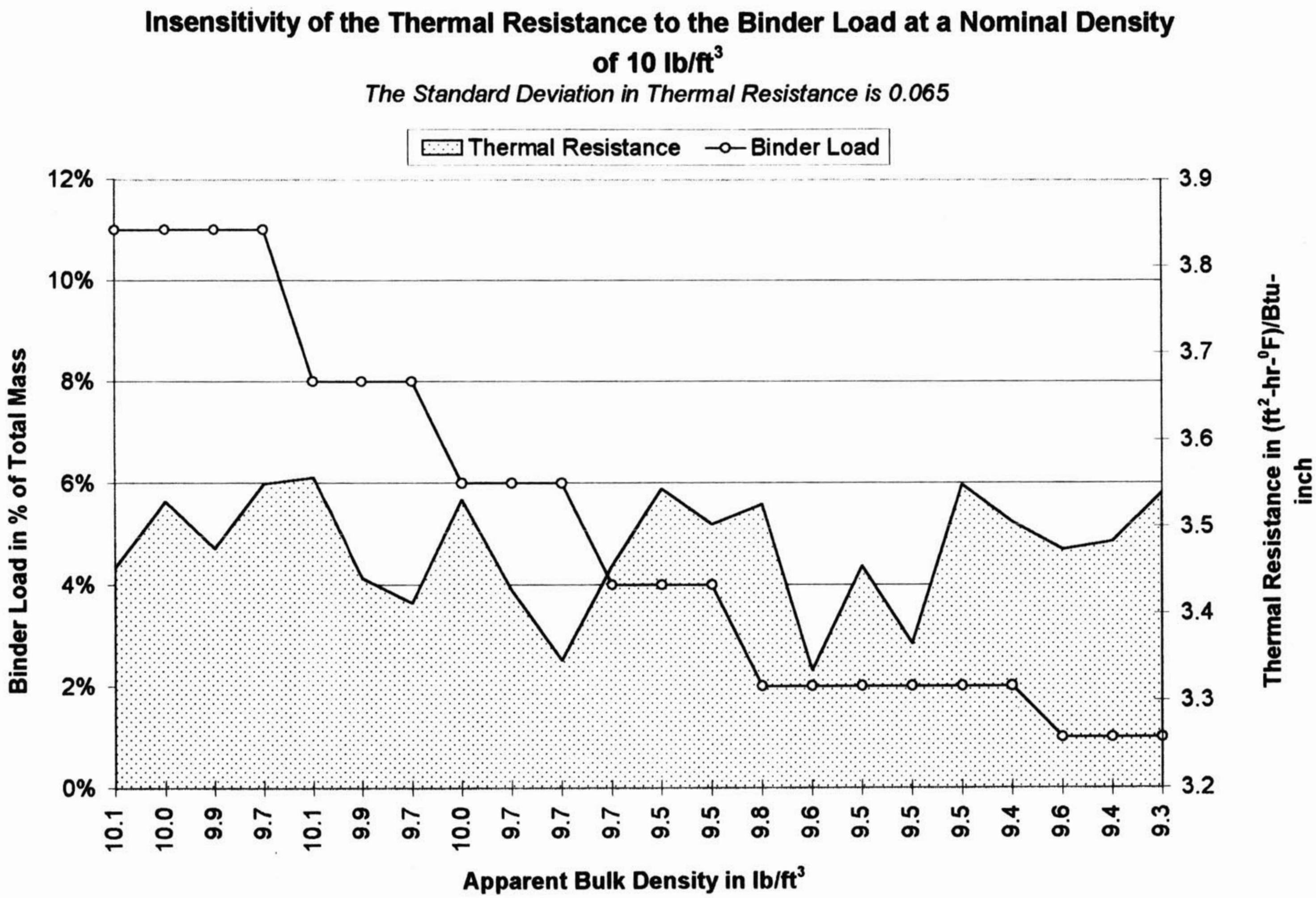


Figure 4-11. Insensitivity of the thermal resistance to binder load at 10 lb/ft³ density

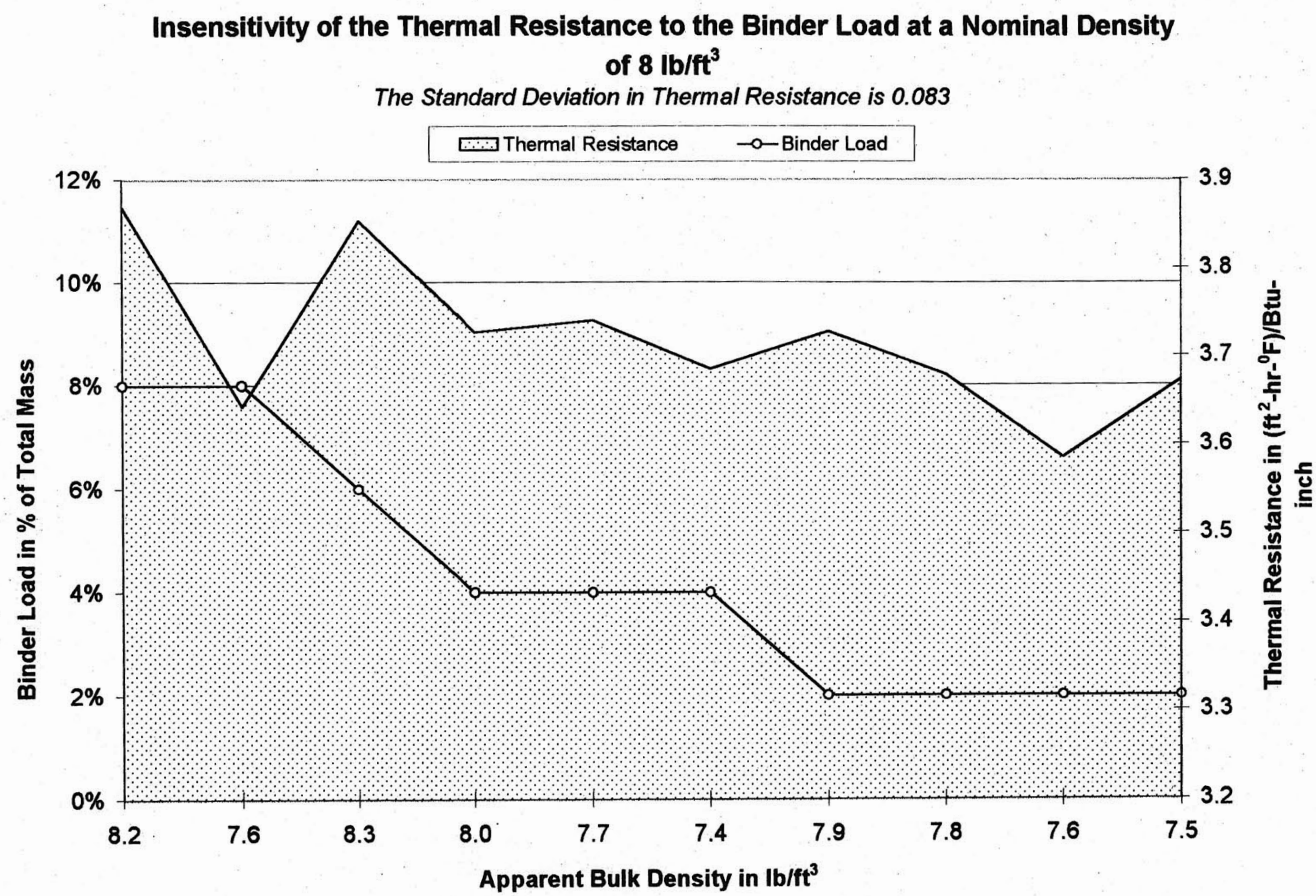


Figure 4-12. Insensitivity of the thermal resistance to binder load at 8 lb/ft³ density

4.2 Structural Performance of Straw Insulation Boards

4.2.1 Qualitative Assessment

The boards fell into fairly distinct structural performance ranges. The qualitative structural assessments for all of the boards are presented in Table 4-1. The properties assessed are the board's surface and rigidity. The surface is described in terms of its flakiness. For the purpose of this assessment of the 25 inch by 15 inch by 1 inch samples, the following criteria were used.

1. A flaky surface sheds straw pieces easily when one's hand is lightly rubbed across the surface.
2. A rigid board does not produce any visible bending or audible cracking when it is held by one corner.

Some lower density boards are referred to as "on-site" production candidates. This signifies that the boards would probably not withstand the stresses or storage and transportation very well. Some of these boards may be strong enough to install and withstand normal building loads if they are manufactured on site. The qualitative adjectives used in increasing value are: awful, poor, fair, good, great, and excellent. "Great" signifies somewhere between good and excellent.

The 15 lb/ft^3 density boards are in a completely different performance class than all the other boards. They exhibit structural properties that could be considered for lightweight wall partitioning systems and furniture uses. The 10 lb/ft^3 to 12 lb/ft^3 density range produced boards with structural properties that could withstand transportation, storage and handling. None of the eight lb/ft^3 boards were suitable for transport and rough handling although some appear suitable for on-site production. In this situation, the boards would be installed immediately after fabrication and would not be subjected to the stresses of transportation. These eight lb/ft^3 boards should not be used in areas with risks of seismic activity. Below eight lb/ft^3, the boards have poor structural and would have no potential value as a board product. This result is most likely related to the specific fabrication process used here. Due to the settled density of the material, good contact could not be achieved with the platen. Microwave heating might be one possible solution to this limitation.

Furnish Type	Nominal Density lb/ft^3	Binder Load % of mass	Bulk Density lb/ft^3	Straw Density lb/ft^3	R-value (hr ft^2 °F/Btu) /inch	Qualitative Structural Assessment
Screened	15	2%	14.3	14.0	2.9	heavy, solid, excellent in every was
Unscreened	15	1%	14.0	13.8	2.8	heavy, solid, different class of material, extremely structural
Unscreened	12	4%	11.7	11.3	3.1	excellent, tough surface, virtually no flaking
Unscreened	12	4%	11.7	11.2	3.2	excellent surfaces for transport
Unscreened	12	4%	11.5	11.1	3.2	great surfaces, extremely rigid
Screened	12	2%	11.3	11.0	3.2	
Unscreened	10	11%	10.1	9.0	3.4	surfaces not so good but good rigidity, solid
Unscreened	10	11%	10.0	8.9	3.5	good overall, 1 half of board is much harder than the other, excellent surfaces on 1/2 of both sides
Unscreened	10	11%	9.9	8.8	3.4	good, more than necessary
Unscreened	10	11%	9.7	8.7	3.5	excellent all around
Unscreened	10	8%	10.1	9.3	3.5	decent surface, excellent rigidity
Unscreened	10	8%	9.9	9.1	3.4	excellent surfaces, great rigidity
Unscreened	10	8%	9.7	8.9	3.4	great surfaces, great rigidity
Unscreened	10	6%	10.0	9.4	3.5	excellent everywhere
Unscreened	10	6%	9.7	9.1	3.4	good/great, ready for market
Unscreened	10	6%	9.7	9.1	3.3	excellent, ready for market
Unscreened	10	4%	9.7	9.4	3.4	excellent rigidity and good surfaces
Unscreened	10	4%	9.5	9.1	3.5	good overall, could be commercial, bottom may need heat or paper
Unscreened	10	4%	9.5	9.1	3.5	excellent rigidity and surfaces
Unscreened	10	2%	9.8	9.6	3.5	good, better than expanded polystyrene
Screened	10	2%	9.6	9.4	3.3	excellent - bottom surfaces a little rough (use heat or paper there)
Screened	10	2%	9.5	9.3	3.4	good overall, needs paper
Screened	10	2%	9.5	9.3	3.3	good overall, not so flaky on the surfaces, top side (heated platen) better than bottom
Unscreened	10	2%	9.5	9.3	3.5	good on-site board, top side not very flaky, fair rigidity

Unscreened	10	2%	9.4	9.2	3.5	fairly rigid and good surfaces
Unscreened	10	1%	9.6	9.5	3.4	fair surfaces, OK rigidity
Unscreened	10	1%	9.4	9.3	3.4	fairly good rigidity, somewhat flaky on the surfaces
Unscreened	10	1%	9.3	9.2	3.5	fairly weak, non-commercial board, flaky bottom
Unscreened	8	8%	8.2	7.6	3.8	fairly flaky on the surfaces, good rigidity, heated side is much better than bottom side
Unscreened	8	8%	7.6	7.0	3.6	
Unscreened	8	6%	8.3	7.8	3.8	flaky on the surfaces, crumbly
Unscreened	8	4%	8.0	7.7	3.7	fairly flaky on the surfaces, not so rigid, good product to make on-site
Unscreened	8	4%	7.7	7.4	3.7	flaky, fair to poor rigidity
Unscreened	8	4%	7.4	7.1	3.6	weak even for on-site production
Unscreened	8	2%	7.9	7.7	3.7	extremely flaky
Screened	8	2%	7.8	7.6	3.6	bad surfaces, decent rigidity, an on-site board
Screened	8	2%	7.6	7.4	3.5	not bad top surface, not rigid, possibly on-site
Screened	8	2%	7.5	7.4	3.6	very flaky on the surfaces, not rigid maybe OK for on-site production
Screened	7	2%	5.6	5.5	3.8	poor
Unscreened	6	11%	5.8	5.1	3.6	awful surfaces, some cohesion
Screened	6	2%	6.0	5.8	3.7	better than some but still poor

Table 4-1. Presentation of all qualitative structural assessments

4.2.1.1 Effect of Binder Load and Furnish on Structural Performance

The qualitative impact of the binder load can described with the phrases:

- more than is necessary
- good
- OK
- not enough

For each density this scale shifted somewhat. For example, at 15 lb/ft^3 density one percent binder load is more than is necessary while at 10 lb/ft^3 density one percent binder load is not enough. For 10 lb/ft^3, the binder scale is summarized in Table 4-2. The bottom surface of the two percent boards is somewhat flaky. This could be fixed by heating both the top and bottom platens during the press cycle. It could also be addressed by applying a Kraft paper facer to that side. This effect was also seen in a less pronounced manner in some of the four percent boards. All of the six percent boards showed commercial quality although it is probably more structure than is necessary for the job. The one percent showed OK rigidity but was generally too flaky on both the top and bottom surfaces.

Binder Load	Qualitative Descriptor
11%	more than is necessary
4% to 8%	good
2% to 4%	OK
1%	not enough

Table 4-2. Binder load effects at 10 lb/ft^3

A qualitative comparison of the two furnish types at 10 lb/ft^3 and two percent binder load shows the unscreened boards to have slightly better surfaces. These surfaces are smoother due to the more thorough mix of fiber sizes.

4.2.2 Static Compression and Flexure Tests of Insulation Board Samples

4.2.2.1 Introduction

The response of a member to loads and the load carrying capacity of materials depends on the type of the loading [Seely and Smith 1956]. The loads generally seen in buildings are static loads. The types of static loads tested here are central compression and three point bending

4.2.2.2 Description of Compression

This method is intended to test board structure in compression. This test is important to determine the range of resistibility of the board to applied loads. The sample is subjected to a uniformly distributed concentric force over the two contact surfaces in the direction normal to the face surface area [ASTM 1994]. The apparatus used for these tests was an Baldwin-Tate-Emery testing machine with a 60,000 lb load cell. The deformation of the sample in response to the load is used to calculate the modulus of elasticity and was measured using a dial gauge accurate to 0.001 inches. The samples used for this test were cut to 4.5 inches square.

Under increasing load, the normal stress, σ, is approximately proportional to strain, ε. Thus, a linear relationship exists between stress and strain. Beyond a point, the *proportional limit*, the material response curve changes shape from strictly linear. If at any point along the linear portion of the stress-strain curve the load is decreased to zero, the board returns approximately to its initial thickness, the material is said to act elastically [Seely and Smith 1956]. For stresses within the proportional limit [Ghaly 1995], we have the relationships

Stress at proportional limit	$\sigma = P' / A$	
Strain at proportional limit	$\varepsilon = \Delta / t$	
Modulus of elasticity	$E = \sigma / \varepsilon$	

where

t	=	thickness
Δ	=	deformation of the thickness of the sample at proportional limit
P'	=	compressive load at proportional limit
A	=	face surface area of board structure

With values for the compressive load at the proportional limit, the deformation of the thickness of the sample, the thickness of the sample, and the face surface area, the modulus of elasticity can be calculated. With our straw board samples, there is no point of rupture for this type of compression normal to the board face area. The force-deflection curves appear linear and shows signs of non-linear growth beginning anywhere from 25% compression and up depending on the particular board (see Figure 4-13). The rigid foam insulation boards force-deflection curves show a different type of behavior. Their curve is linear to between 10% to 15% compression and then the stress either plateaus or declines (see Figure 4-14).

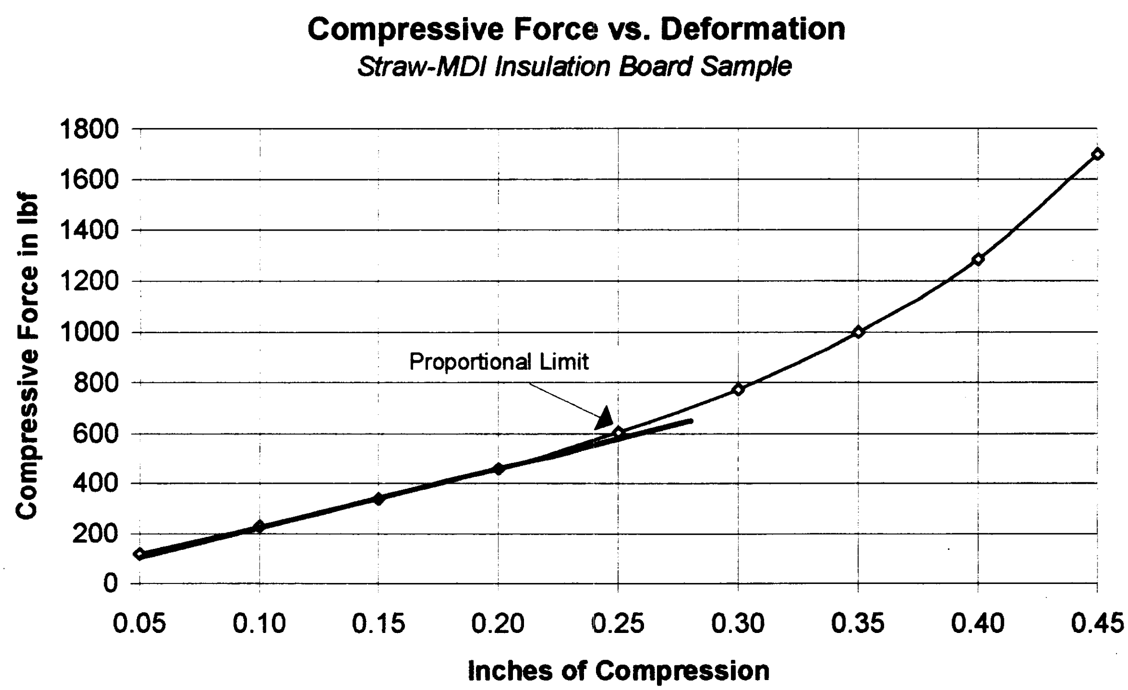


Figure 4-13. Example of the straw-MDI resistance to compression

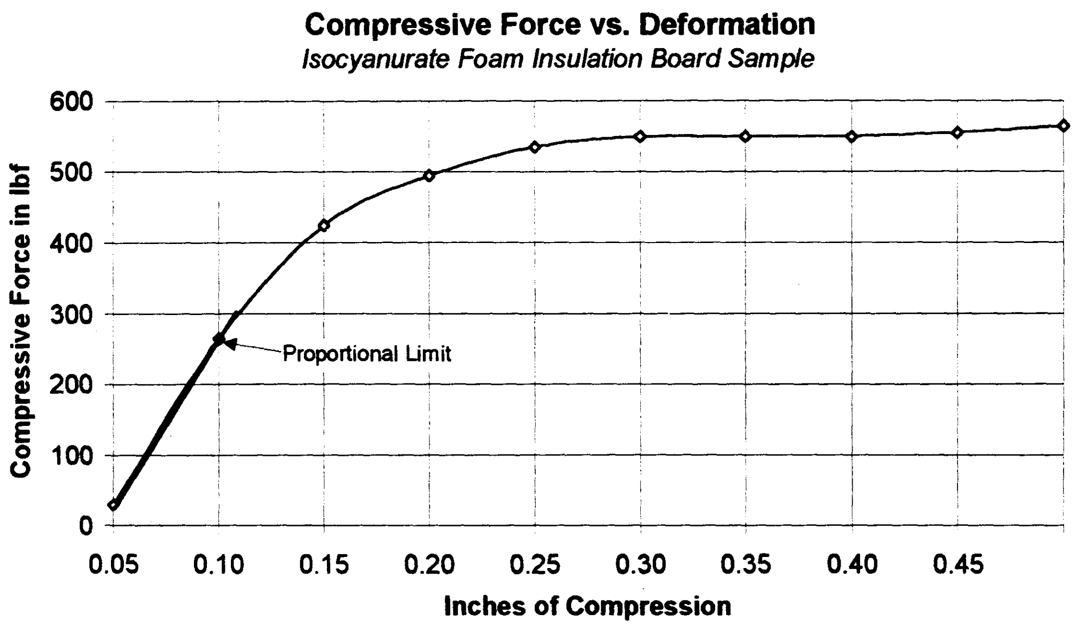


Figure 4-14. Example of a rigid foam insulation board resistance to compression

4.2.2.3 Compression Resistance Results

The samples' structural resistance was compared at compression to 10%, 15%, 20% and 25% of the initial thickness. These moduli of elasticity are presented in Figure 4-15 and Figure 4-16. Included in these figures are comparisons with commercial products: extruded polystyrene, isocyanurate, fiberboard (specified as a "roof" insulation board), and expanded polystyrene.

At 10% compression, the screened-two percent and the unscreened-four percent 10 lb/ft^3 boards show nearly identical performance, closely followed by the unscreened-two percent board. In Figure 4-17, the 10 lb/ft^3 nominal density boards are examined in greater detail. A visible trend that should be noted here is the apparent elongation of the linear elastic region for boards at binder loads of four percent and higher. For the boards with smaller regions of linear elastic response, the force required to further compress them increases. This is the region of increasing slope shown in Figure 4-13 at 0.3 inches of compression and higher. In fact at 25% compression, the unscreened-two percent board shows a slightly higher resistance than the unscreened-four percent board; the unscreened-four percent is stronger than the unscreened-eight percent board and the eight percent is stronger than the unscreened-11% board. The close proximity of the moduli at 10% and 25% compression for the four percent, eight percent, and eleven percent binder samples indicates that these boards are still in their linear elastic region of performance. In the one and two percent samples, a much greater difference is seen between the moduli at 10%

and 25%.[8] This means that these boards are outside of their linear elastic region at 25% compression. A final interesting point to observe is the relationship with the observation is the relationship between the linear elastic region and the straw and bulk densities. For the one and two percent boards, the straw density is much closer to the bulk density than for the boards at higher binder loads. The significance of this observation is that the cured binder imparts elasticity to the boards, causing the board to elastically resist compression over a greater range of deformation.

The majority of the boards have moduli greater than 50 psi. This means that it requires at least five psi of normal stress to compress the boards to 90% of their initial thickness. Five psi is equal to 720 lbf/ft^2. At a density of 10 lb/ft^3, this force is equal to a stack of panels 72 feet high in the air. This is well beyond the normal loads these boards are likely to experience during storage periods. Five psi is also equal to the stress that would result if a 150 lb person with a 10 inch by three inch foot were to step on a board at some point before installation. Indeed most of the 10 lb/ft^3 boards have moduli closer to 150 psi. These boards require at least 15 psi of normal stress to compress the board to 90% of its initial thickness. Fifteen psi is equal to a 216 foot tall stack of boards to compress the bottom board by 10% of its initial thickness. In terms of footstep stress, 15 psi is equal to a 450 lb person stepping on the board with a 10 inch by three inch foot or is equal to the stress of a 135 lb person putting all of their weight down on the three inch by three inch ball of their foot.

The comparisons are summarized for resistance to 10% compression in Figure 4-18 and resistance to 25% compression in Figure 4-19. Rigid fiberglass board has been omitted from the percentage change figures because its structural performance is so low that including it obscures the other results. From these figures it is obvious that the 14.3 lb/ft^3 bulk density board is in a different class of materials. At 10% compression, the elastic modulus is 586% greater than that of expanded polystyrene and 31% greater than the extruded polystyrene. Of the other materials, the extruded polystyrene shows the best resistance to compression at 10%. Expanded polystyrene exhibits the least resistance closely followed by the eight lb/ft^3 density, unscreened furnish boards. Beyond 10% compression, the cellular structure of the extruded polystyrene begins to collapse and the largest resistances to compression are found in the cellulosic boards of 10 lb/ft^3 nominal density and higher. The straw boards in this density range perform better than the fiberboard sample at 10% compression, but only the 11.3 lb/ft^3 boards continue to lead at 25% compression.

[8] The term modulus usually refers to the linear region of the force vs. deflection curve. Therefore the value of the modulus (slope of the curve) should be nearly constant. The large change in modulus described in the text is used to indicate the termination of the linear elastic region.

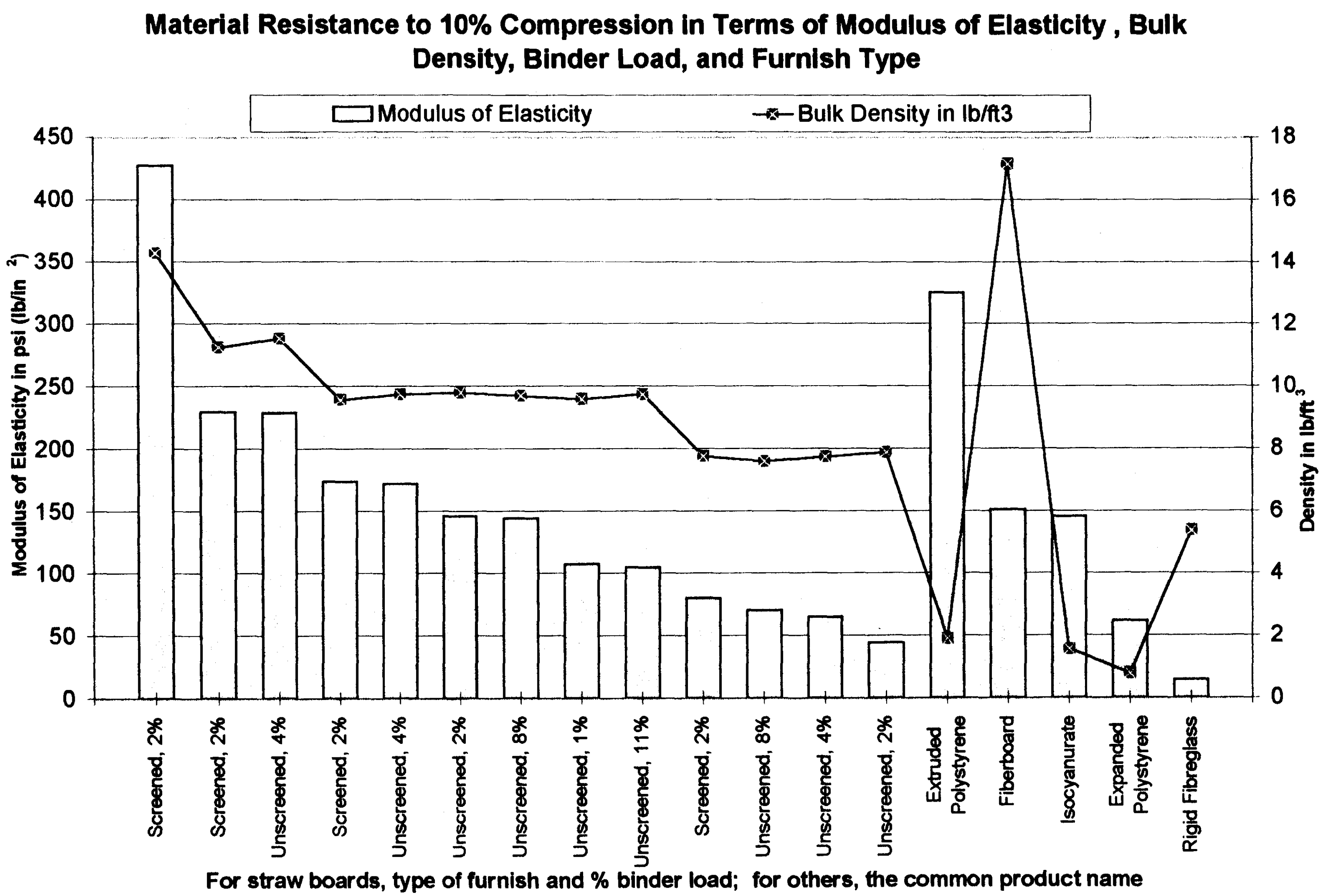


Figure 4-15. Material resistance at 10% compression

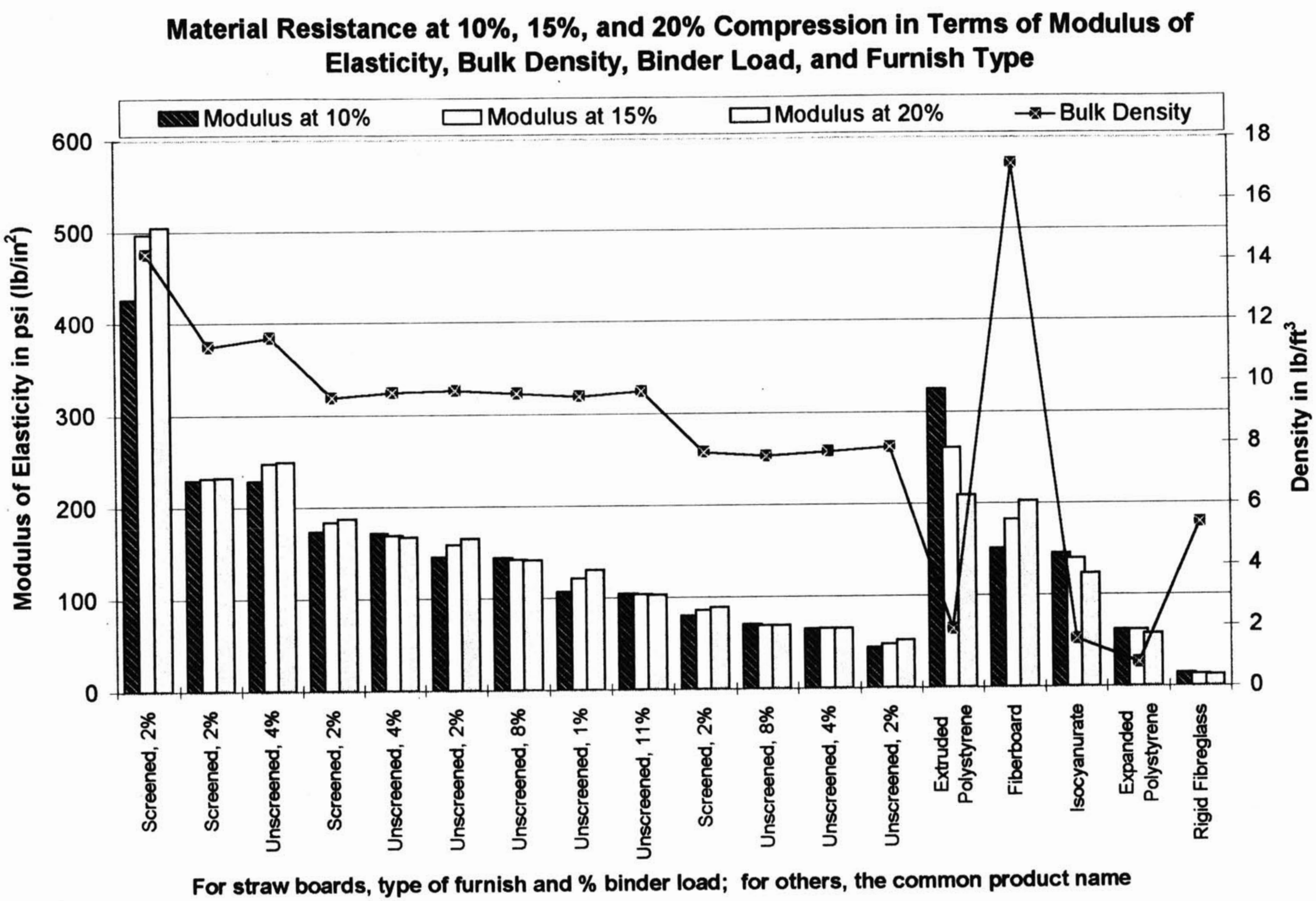


Figure 4-16. Material resistance at 10%, 15%, and 20% compression

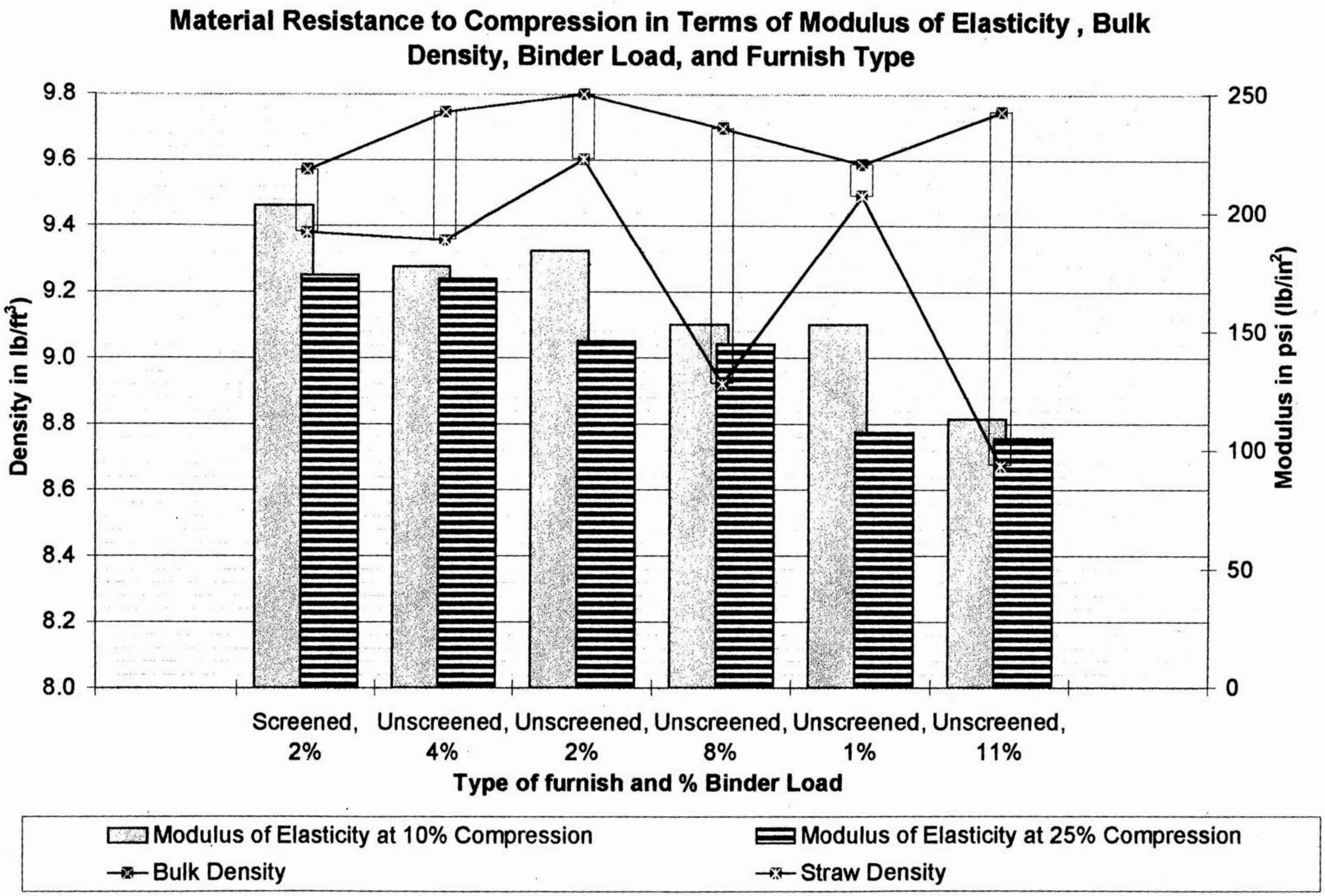


Figure 4-17. Material resistance comparison of the 10 lb/ft^3 boards

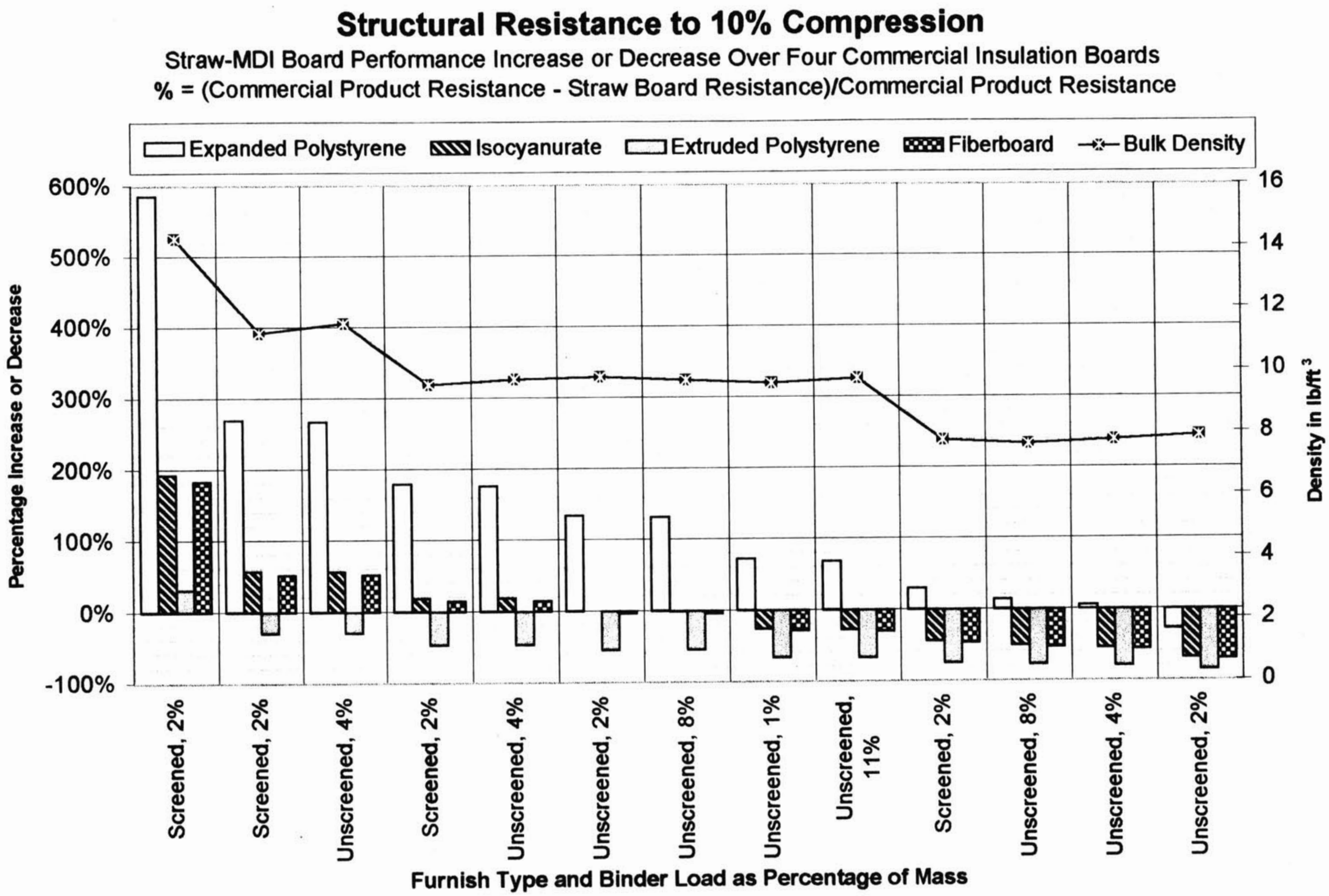


Figure 4-18. Percentage change in resistance at 10% compression vs. commercial products

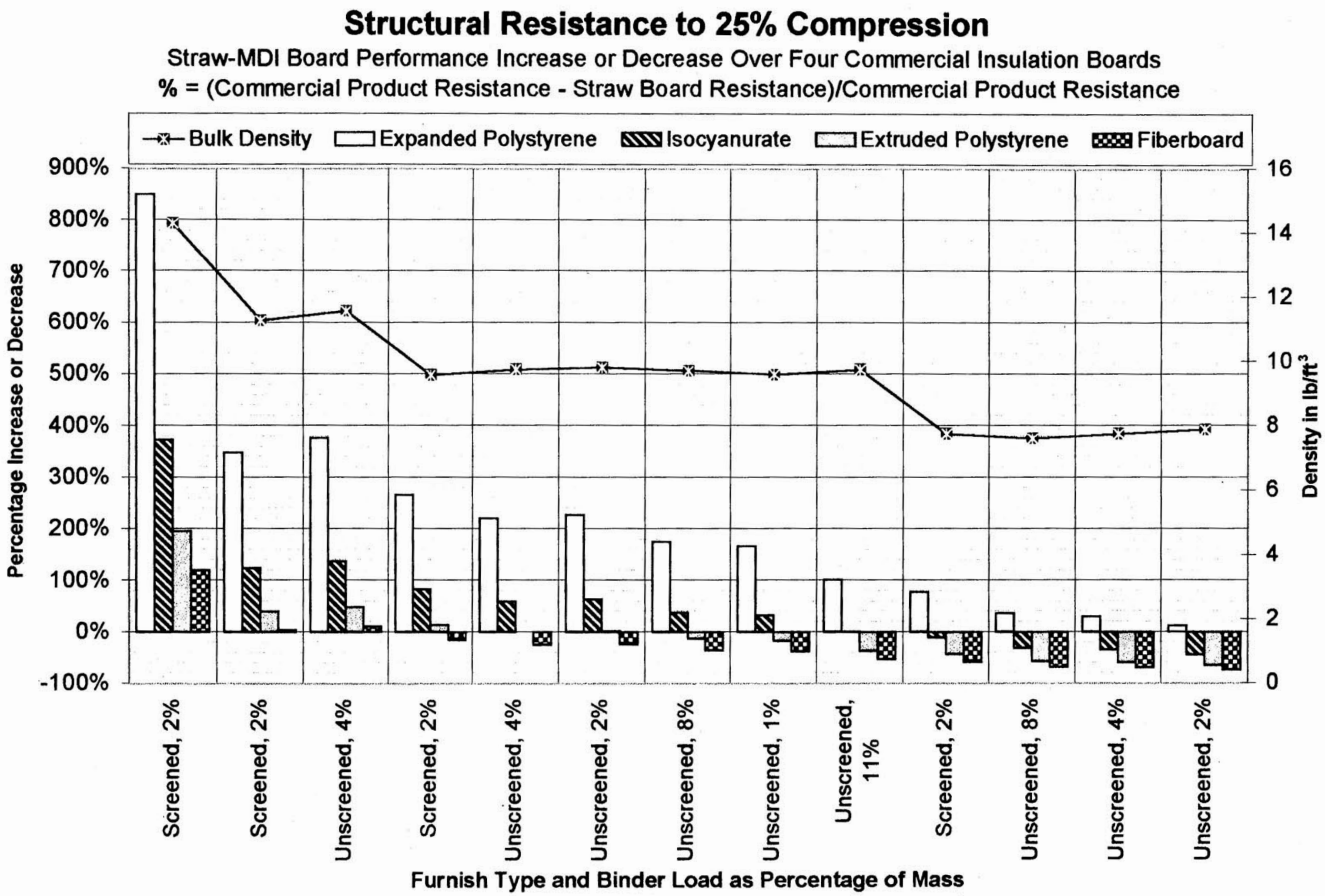


Figure 4-19. Percentage change in resistance at 25% compression vs. commercial products

4.2.2.4 Description of Flexure Testing

In this experiment, the boards were cut into beams with dimensions of approximately 6.5" long by 2.5" wide by 1.0" thick. A sample beam was supported on the two ends using knife edges, at zero and six inches. The bending load was applied to a single line in the center at three inches. This type of bending is termed *ordinary bending* and develops both shear and normal stresses on a transverse section. Evaluation of flexural resistance of boards is necessary to determine the loads that these sections can resist before rupture [Ghaly 1995]. This data is useful for making specifications and evaluating working stresses, influence of imperfections, influence of fiber length concentration profiles, and density. This information can also be used to optimize the product for performance requirements in terms of resistance to storage loads, transportation, handling, installation, and lifetime loads. An Instron structural testing machine with a 1000 lb screw-actuated frame was used to perform these tests. The accuracy of the apparatus had been previously calibrated to within 1% accuracy in accordance with ASTM standards.

The beam dimensions, the load up to and at failure, and the deflections corresponding to measured loads are recorded. These values are then used to calculate the stress at rupture, the stress at the proportional limit, the shear stress at rupture, and the modulus of elasticity [ASTM 1994]:

a	=	distance from reaction to load point, half of the deflection span
w	=	width of beam
t	=	thickness of the bead
l	=	span of the beam used to measure deflection
L	=	total span of beam
P	=	maximum transverse load on beam
P'	=	load at proportional limit
τ_m	=	shear stress of beam
Δ_l	=	deflection of beam measured at midspan over the distance of the beam (l).

Stress at prorpotional limit, $S_F = \dfrac{3P'a}{wt^2}$

Stress at rupture, $S_R = \dfrac{3Pa}{wt^2}$

Modulus of elasticity, $E_G = \dfrac{3P'al^2}{4wt^3\Delta_l}$

Shear stress, $\tau_m = \dfrac{3P}{4wt}$

A sample plot of the material resistance curve for this flexure test is given in Figure 4-20. The rupture point occurs at 4.3 mm of strain extent (Δ_1) and 14.4 N of force (P). The proportional limit is denoted by P'.

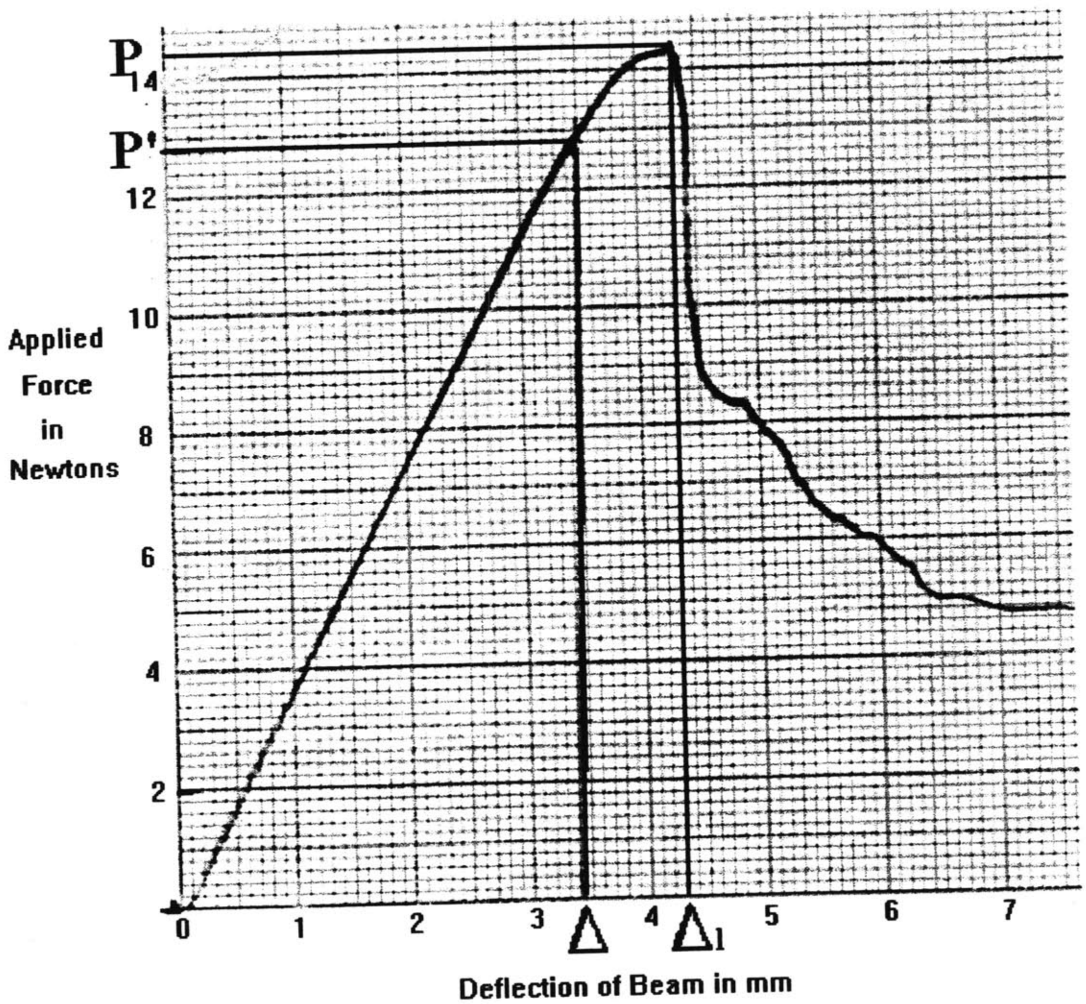


Figure 4-20. Sample force-deflection curve showing the proportional limit of the material

4.2.2.5 Flexure Test Results

Isocyanurate is most commonly sold with foil facers on both surfaces. This foil was removed for the structural tests. The reasons for this are that the comparison is focused on the fundamental material properties and indeed foil facers can be added to any of the board types.

The stress at rupture and the proportional limit are presented in Figure 4-21. The percentage change in stress at rupture of the straw boards over the commercial benchmark boards is presented in Figure 4-22. As in compressive resistance, the 14.3 lb/ft^2 sample proved to be in a different material class. The 11 lb/ft^3 samples withstood stresses ranging between 62% greater than that of extruded polystyrene to 753% greater than that of expanded polystyrene.

In the 10 lb/ft^3 range, only the screened-two percent sample withstood a greater stress than extruded polystyrene. The unscreened-four percent sample fell 10% below extruded polystyrene and 12% above isocyanurate. The unscreened-eight percent board fared better at only seven percent below extruded and 15% above isocyanurate. The unscreened-11% board came in below this at 21% below extruded and three percent below isocyanurate although still 212% better than expanded polystyrene. This trend suggests an optimum binder load near six percent to seven percent to maximize the rupture stress resistance with the unscreened furnish.

The curve for the stress at the proportional limit closely follows the stress at rupture curve although it is offset by approximately -10% for densities above eight lb/ft^3. The shear stress at rupture is presented in Figure 4-23. The shear stress is generally about 10% of the rupture stress for these samples. The shear stress measure is not very significant in this flexure test beyond acknowledging that shear stresses are present. In this test, shear stresses play a minor role relative to the tensile and compressive stresses.

The moduli of elasticity for the flexure tests are presented in Figure 4-24. The percentage increase or decrease of the of the straw board performance over the commercial benchmarks is presented in Figure 4-25. The interesting change described by these figures is that of the 10 lb/ft^3 samples, the unscreened-eight percent boards has the greatest modulus of elasticity in flexure. This board is followed by the unscreened-11% board and then the screened-two percent board. All of the 10 lb/ft^3 boards are equal to or stronger than extruded polystyrene by this measure except for the unscreened-one percent board which is 52% below the value for extruded. The unscreened-two percent is 10% greater than extruded polystyrene while the screened-two percent is 18% greater. By this measure, all of the straw boards are stronger than expanded polystyrene; the weakest board being 215% greater.

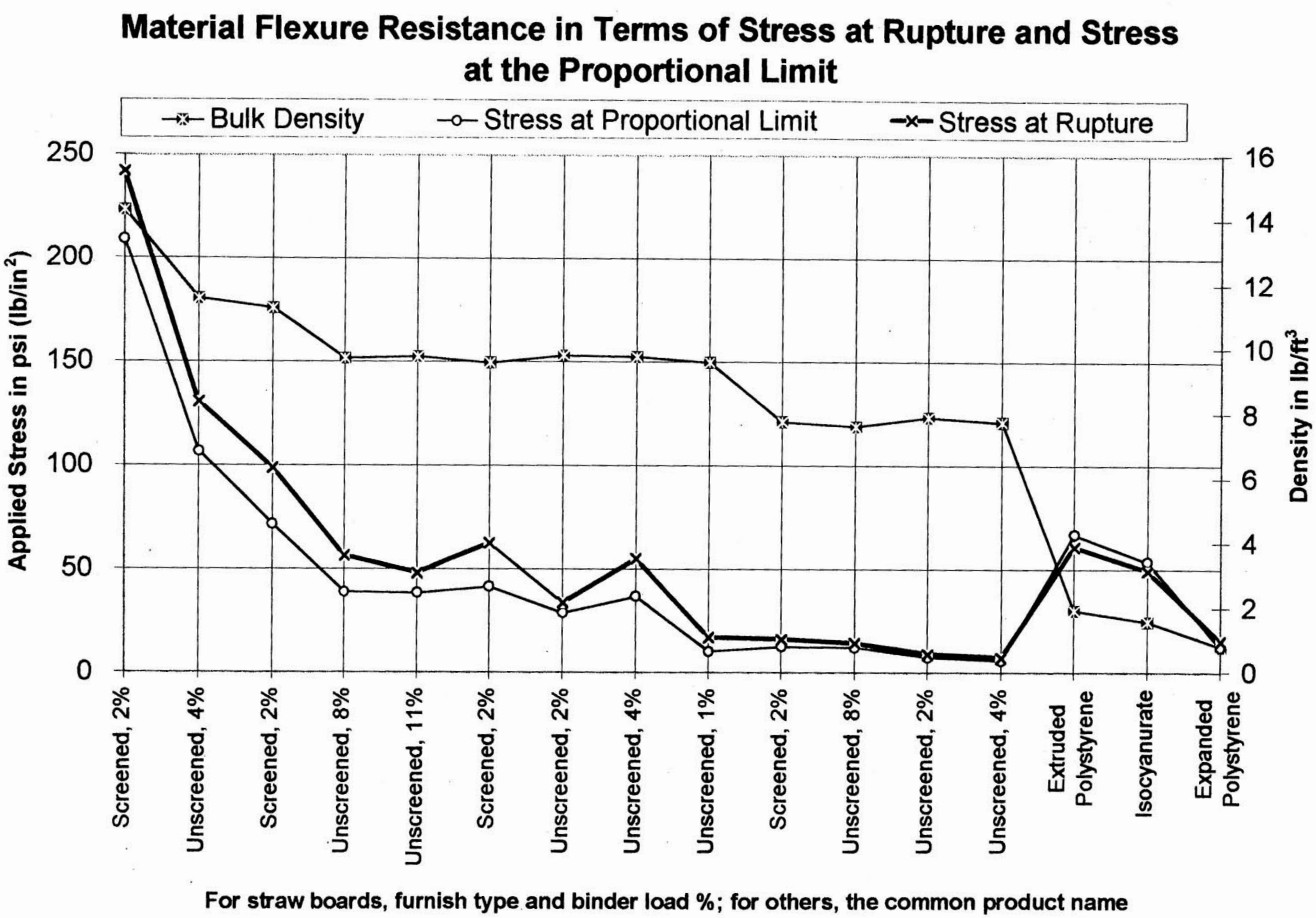


Figure 4-21. Stresses at rupture and the proportional limit

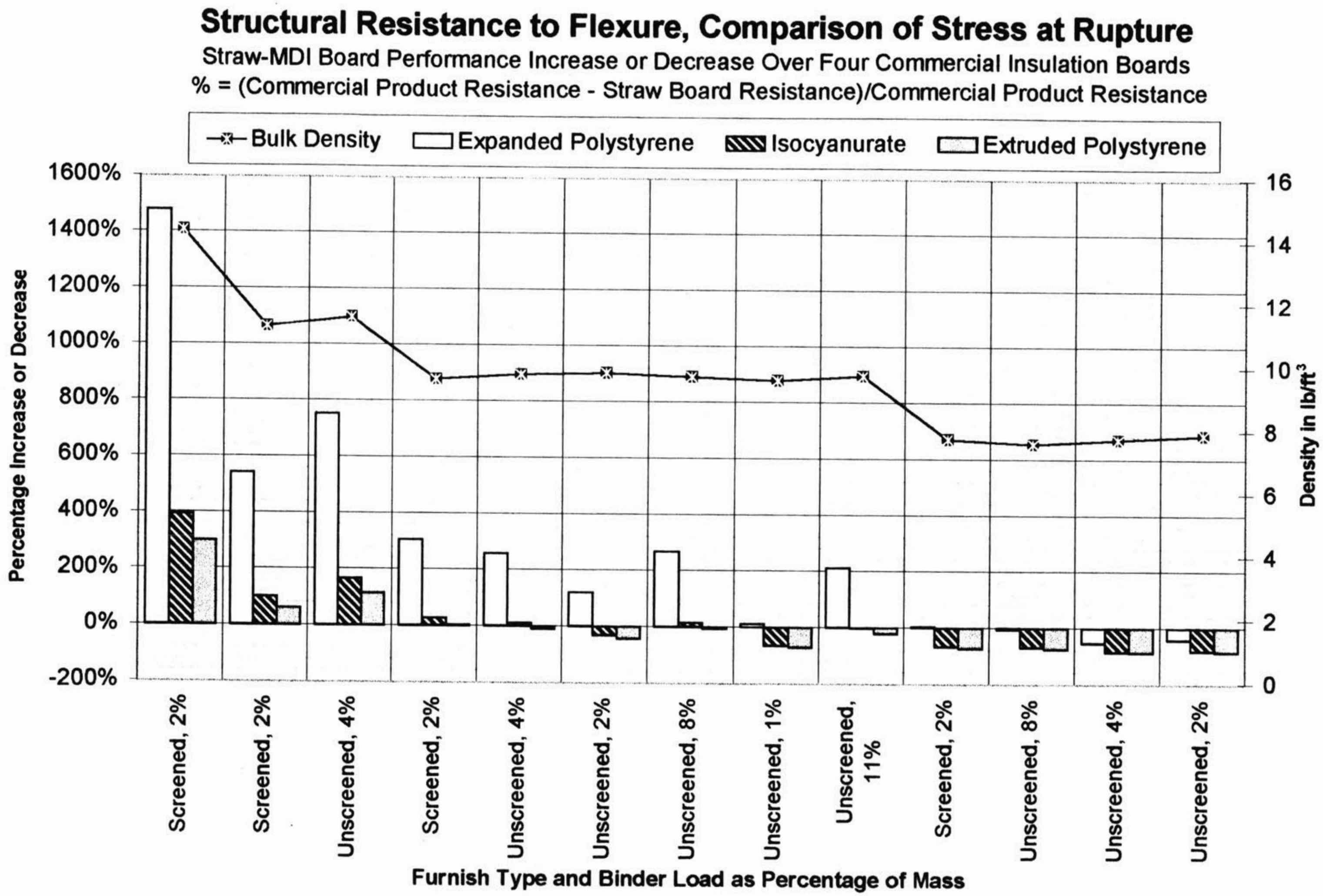


Figure 4-22. Percentage change in flexure stress at rupture vs. commercial products

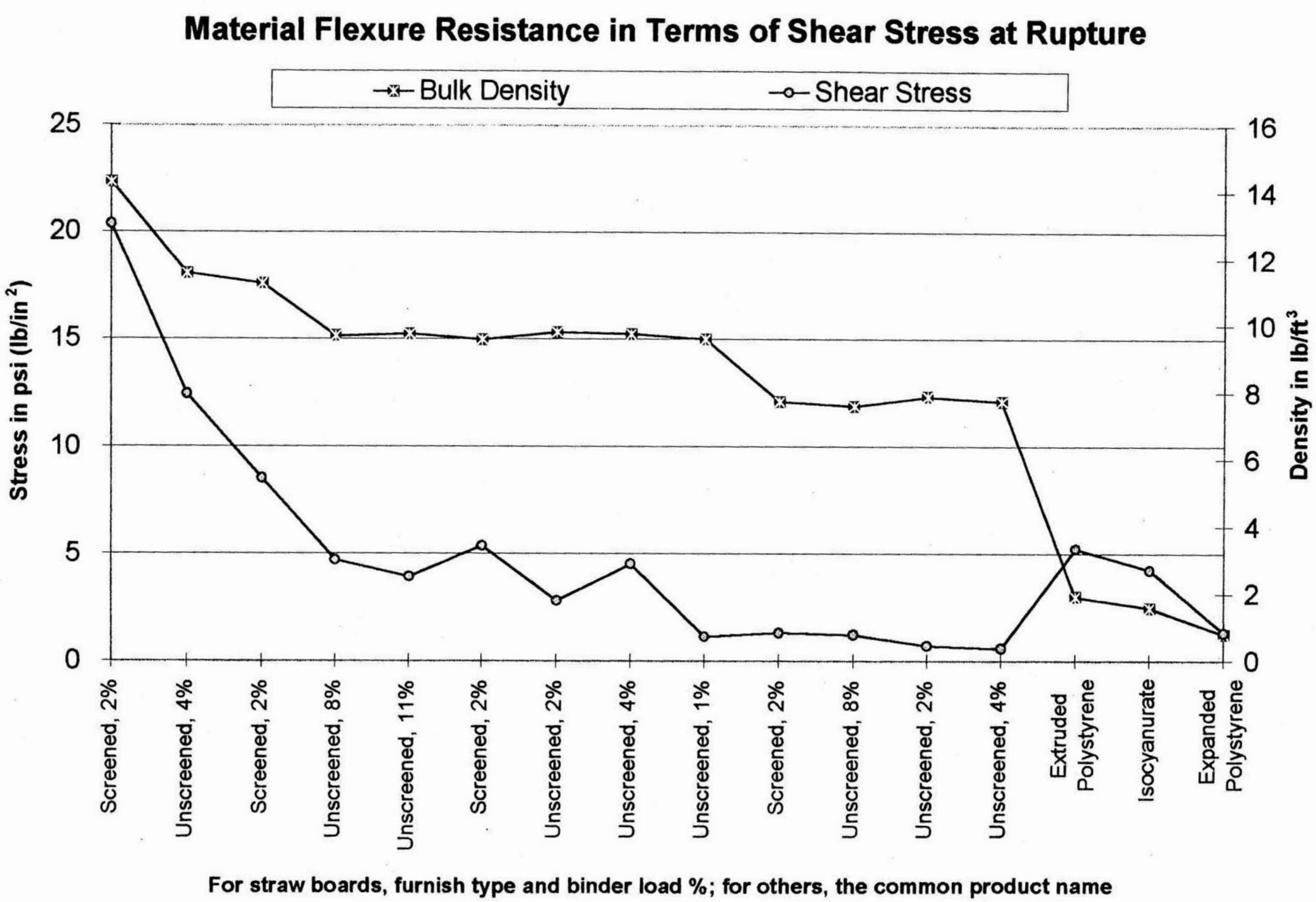


Figure 4-23. Shear stress at rupture

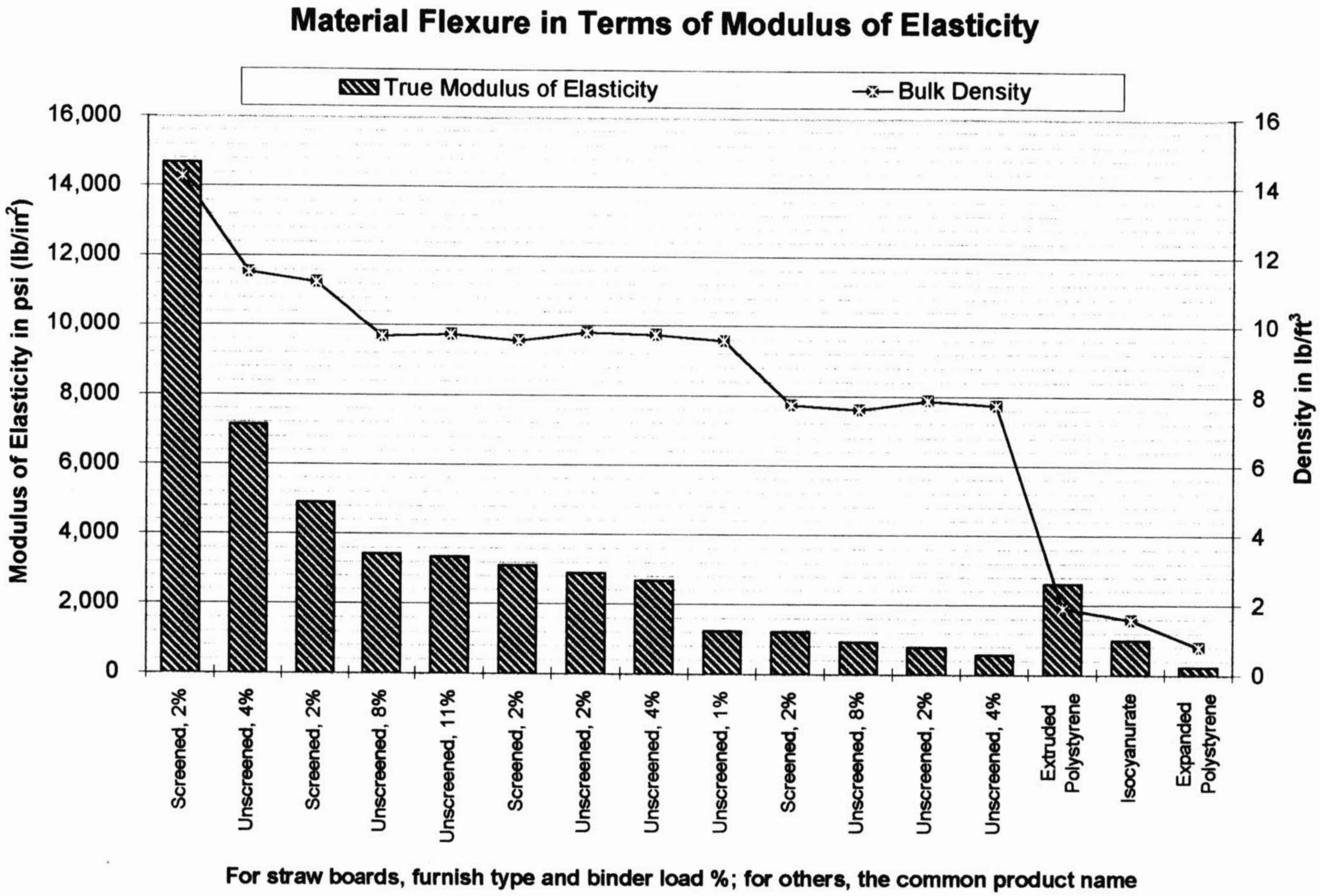


Figure 4-24. Material flexure comparison in terms of modulus of elasticity

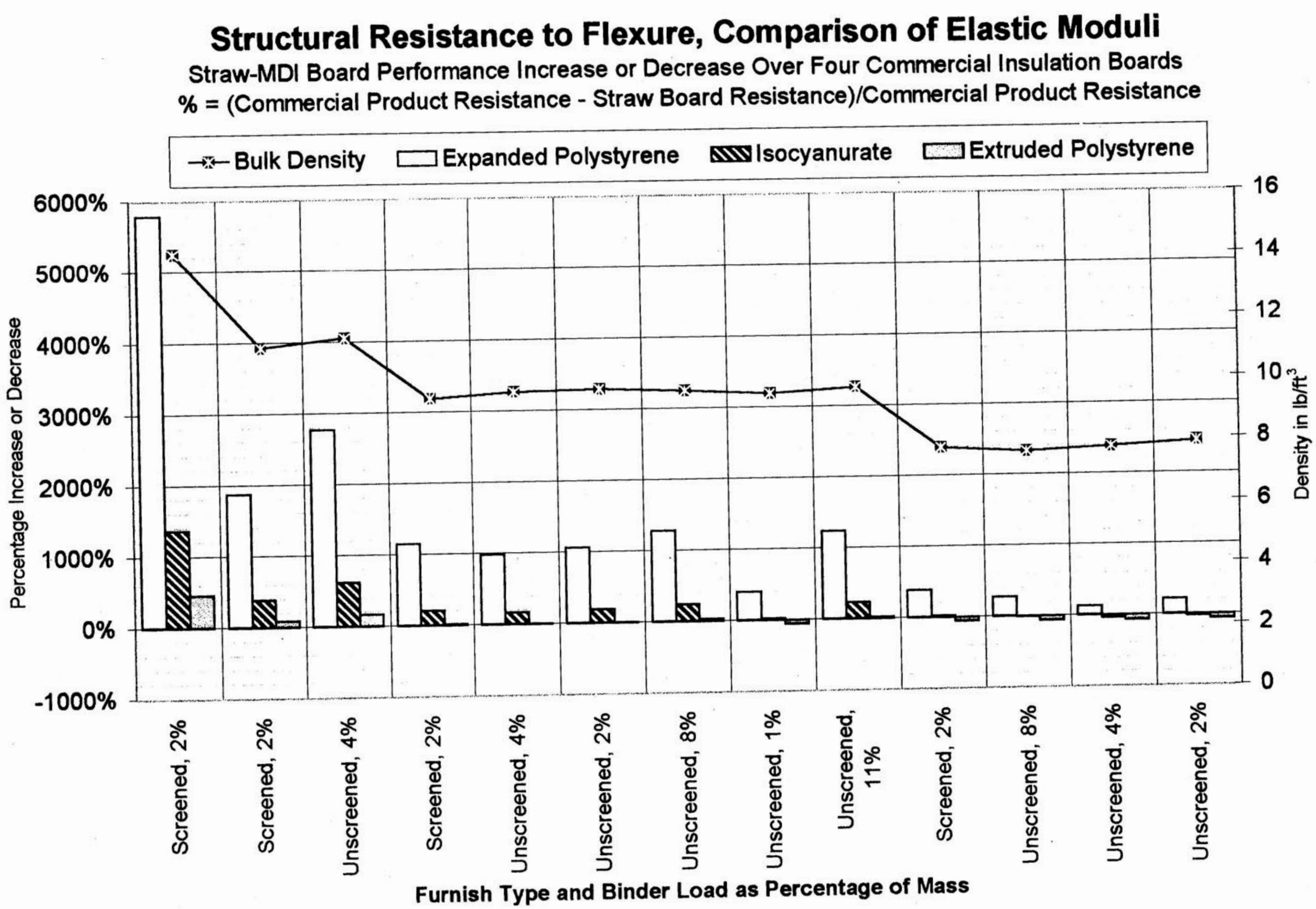


Figure 4-25. Percentage change in flexure modulus of elasticity vs. commercial products

4.2.2.6 Summary of Structural Analyses

All the boards presented here outperform expanded polystyrene in a majority of the tests. However it is clear from the qualitative analysis that the eight lb/ft^3 boards require some kind of facer or extra processing to control for unacceptable flakiness and "shedding" from the surfaces. Density has much a stronger impact on the structural performance than does percentage binder load. By most tests, the screened material does indeed produce stronger boards at the same binder load and density. It should be noted however, that the boards only need to perform in accordance with the expected process. If the boards were to made at the construction site, the material strength requirements would most likely be reduced.

4.3 Economic Cost Analysis

We use the cost per unit thermal resistance to compare the alternative board products which is US cents per square foot at the R-1 insulation level or ¢/R-ft^2. This ensures that we are always comparing cost at the same level of thermal performance. To interpret the cost per insulating unit in this analysis, bear in mind that in the United States, loose fill cellulose and batt fiberglass cost about 1-2 ¢/R-ft^2, expanded polystyrene about 4 cents, and extruded polystyrene and polyurethane about 6 cents. In the target market of northern Pakistan, expanded polystyrene costs approximately 6 ¢/R-ft^2.

To evaluate the commercial viability in a given market requires consideration of many variables. For northern Pakistan we have developed a simple material cost analysis that does not incorporate labor costs. A slightly more detailed economic analysis for northern Pakistan that attempts to incorporate labor costs is presented in Part II of this thesis in Section 7.3. In reality there are many extra costs which affect the retail price. Some of these extra costs are outlined in Table 4-3.

Item	Percentage Increase Over Material Burden
Overhead	15%
Labor	20%
Margin	20%
Sales Markup	4%
Retail Markup	20%

Table 4-3. Business cost contributions to end-user price

These extra costs can raise the retail by 100% of the material cost and beyond. For this reason, I have chosen 2 ¢/R-ft^2 as a reasonable threshold limit for board material cost per R-ft^2. This cutoff point ensures that the resulting boards will still be extremely cost-competitive with existing board products like expanded polystyrene.

In our experiment, we used the heat-curing binder with a heated press. For this economic analysis however, rather than attempt to quantify the additional cost of heat for each board I have simply used the cost for the air temperature curing binder which is 50% higher. I am assuming the air temperature curing binder performs identically to the heat-curing formulation. The economic analysis has been performed using the cost of straw in northern Pakistan and a cost estimate for air temperature curing MDI provided by ICI Polyurethanes. An analysis has also been performed based on US straw prices. These costs are presented in Table 4-4.

Material	Unit Cost in US \$ per pound
Straw in northern Pakistan	\$0.053
Straw, potential range in the United States	\$0.014 to \$0.043
Polymeric MDI Resin - Heat Cure	\$1.000
Polymeric MDI Resin - Air Temp. Cure	\$1.500

Table 4-4. Material cost table [Sullivan 1995; USDA 1994; ICI Polyurethanes[9]]

The results of this analysis are presented in Figure 4-26. An important result to note here is that all forty-one of the straw-MDI boards fall below the 5.3 ¢/R-ft^2 material cost mark so they are all initially appear less expensive than the expanded polystyrene benchmark for northern Pakistan. Seventeen of these boards, 41%, meet the 2 ¢/R-ft^2 threshold criterion. Comparing this range with the qualitative structural analysis yields the entire set of both screened and unscreened 10 lb/ft^3 nominal density boards at two percent binder loading. The unscreened 10 lb/ft^3 boards are ready for implementation without requiring further optimization. At a given density, the screened boards will provide better structural performance than the unscreened but will require more straw overall. The extra material burden required to produce screened material is shown by the y-error bars in Figure 4-26. The cost of the screened furnish boards may be depressed by approximately 21% depending on the fate of the fines. The 21% estimate is the percentage of material that has been removed from the unscreened furnish (33% fines) to "de-fine" the screened furnish (12% fines). The fines can be burned as heating fuel and could potentially be used directly to provide the necessary heat to cure the less expensive formulation of Polymeric MDI. Another potential uses for the fines include addition to the board's outermost layers to achieve a smooth surface finish. The four percent boards at 10 lb/ft^3 fall in a slightly higher cost range around 2.5 ¢/R-ft^2. The single 12 lb/ft^3 board at two percent binder loading is fairly competitive at 2.4 ¢/R-ft^2 and may be worth considering for applications where a higher strength insulation board is desired.

For the eight lb/ft^3 nominal density, all of the one percent to two percent boards and most of the four percent meet the economic objective. However even the most structurally sound of these eight lb/ft^3 boards would require an alteration in the process such as paper facers, higher surface binder load, or on-site production methods to make them feasible. The benefits of the lower density are higher thermal performance per inch thickness and lower overall straw material burden.

[9] Price quote from ICI Polyurethanes Group, a business unit of ICI of Americas, Incorporated, Deptford, New Jersey.

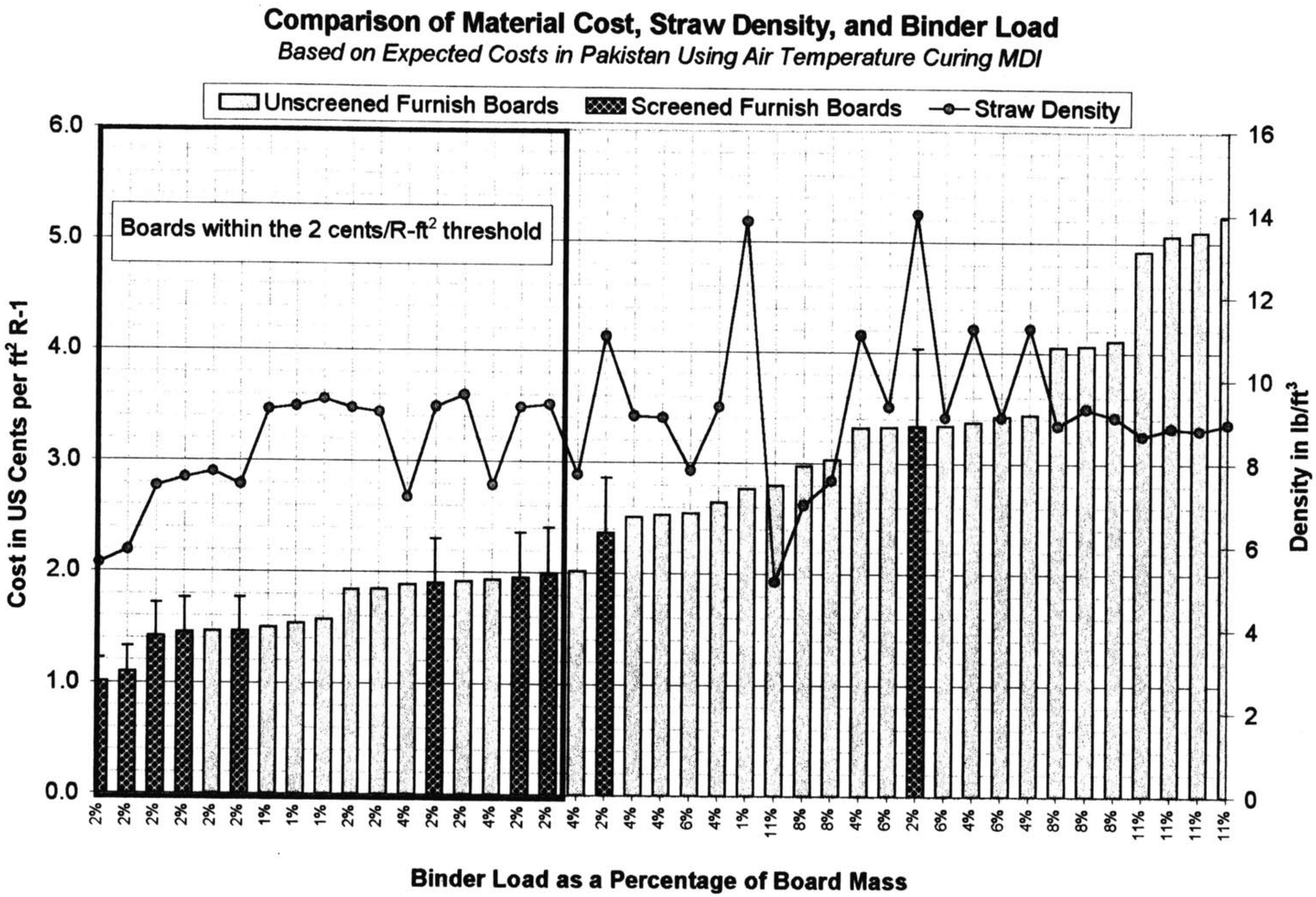


Figure 4-26. Economic analysis of the straw-MDI boards

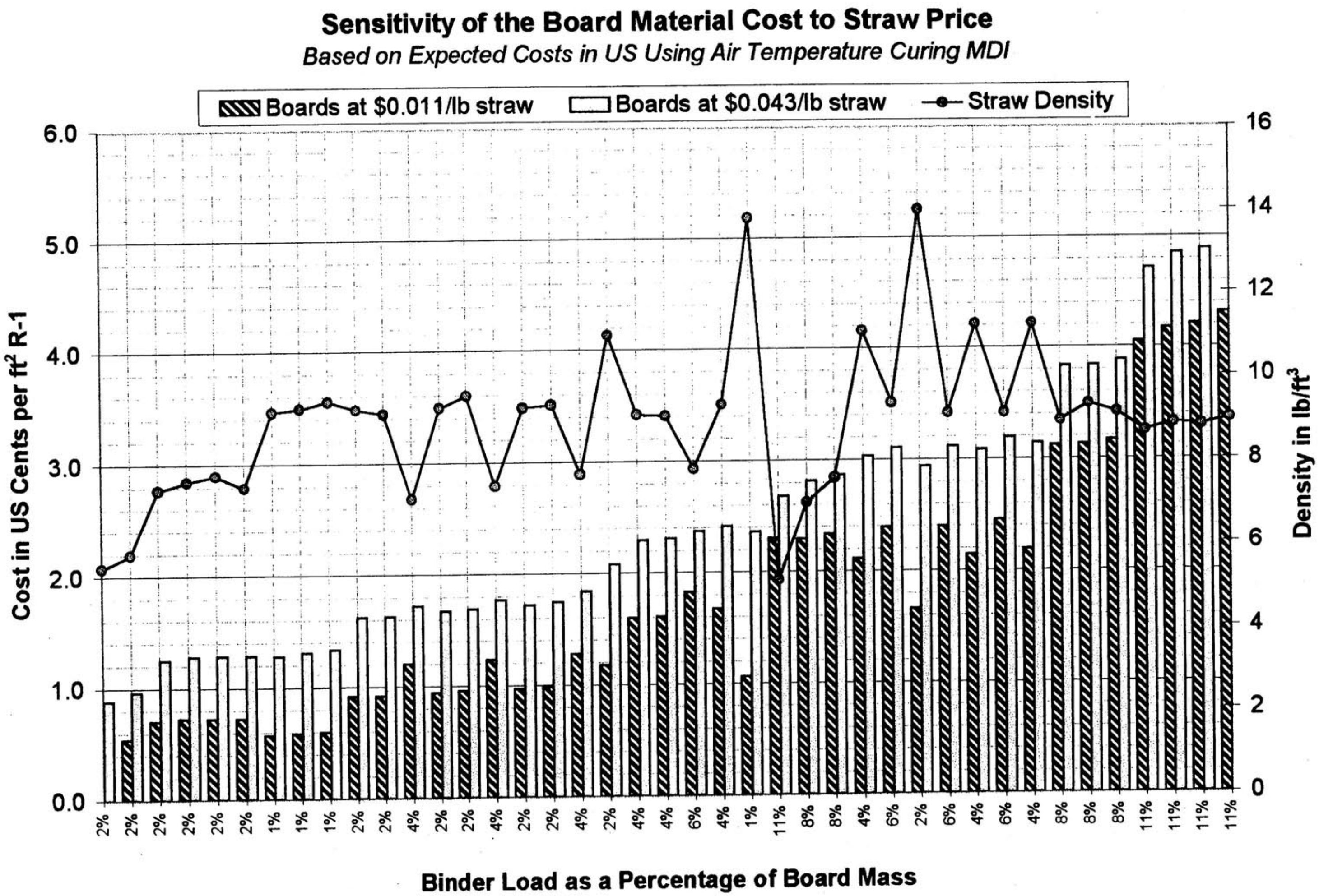


Figure 4-27. Board material cost sensitivity to the price of straw.

4.3.1 Material Cost Sensitivity

The price of any agricultural byproduct depends on the proximity to the area of harvest (collection and transportation) and the competing uses for the material (demand). In the New England region of the US, straw is imported from Canada at a cost of around \$4/bale; a bale is estimated to weigh about 70 lb.. In the US, it has been estimated that 50% of the straw is not used or harvested [Tyson 1992]. Currently the straw produced in the straw belt regions has little demand and its current cost is only a function of baling and transportation costs [Pettijohn and Lorenz 1995]. In the past, the excess straw was burned in the fields. Due to environmental regulations and air quality concerns in many states , burning has been replaced by transport to landfills. In most areas of the US, plowing the straw into the soil requires twice as much work as regular plowing and can negatively impact crop yields by robbing the soil of nitrogen. In Washington and Oregon however, a higher percentage of the straw can be plowed back into the soil due to the regional soil chemistry. The sensitivity of the straw-MDI insulation board material burden to the price of straw is presented in Figure 4-27 for straw costs of \$0.011 and \$0.043 per pound. The lower price is an average for Kansas and North Dakota [USDA 1994] and the upper is a more common bulk price in other US regions. At \$0.011/lb, the range of boards that satisfy the 2 ¢/R-ft^2 criterion is extended to 61% of the experimental group.

4.4 Summary

The results are very promising. Overall, the unscreened, two percent binder load, 10 lb/ft^3 density boards provide the optimal balance of thermal, structural, and economic performance. Selection of the optimal board type may vary according to specific application requirements. The straw boards readily accept direct application of a surface finish plaster. The plaster should provide a fire retarding barrier if one should be necessary. Indeed the material composition of the straw-MDI boards is similar to plywood and we do not anticipate any special fire safety requirements for its use in buildings. However if more robust fire retarding is desired, borates could be added to the straw-MDI material formulation. Borates are a common additive to loose fill celulosic material to impart some degree of fire retardance. If this was deemed necessary for the straw-MDI boards, the optimized material formula might have to be altered to maintain the current level of structural performance.

One board composition which was not fabricated here was a 10 lb/ft^3 board at one percent binder load with screened furnish. This cost of this board would probably fall within the 2 ¢/R-ft^2 limit given the current material cost data.

It is important to note as material supplies (costs) change, the ranking of the board types that optimally satisfy the structural and economic cost per unit thermal resistance objectives may change as well. If for example the straw cost was to plunge, higher density boards with lower binder content may be preferred. However there is a thickness penalty paid to achieve the same thermal performance with higher density boards. In situations where real estate costs are paramount such as in New York City, more analysis would need to be performed to assess the tradeoff between lower insulation material cost and the additional real estate cost of the increased wall thickness.

One limitation of the heat-cure process is the thickness of the board. We attempted to fabricate a 4 inch thick board and experienced difficulty with binder curing. In this case the thermal resistance of the board inhibited the necessary temperature rise on the bottom platen surface which was unheated.

The boards can be easily installed in new or existing masonry construction. Several techniques for installation have been tested such as utilizing masonry screws to either fasten metal brackets to the wall or to support a network of twine in tension; an example of the metal brackets technique is shown in Figure 4-28.

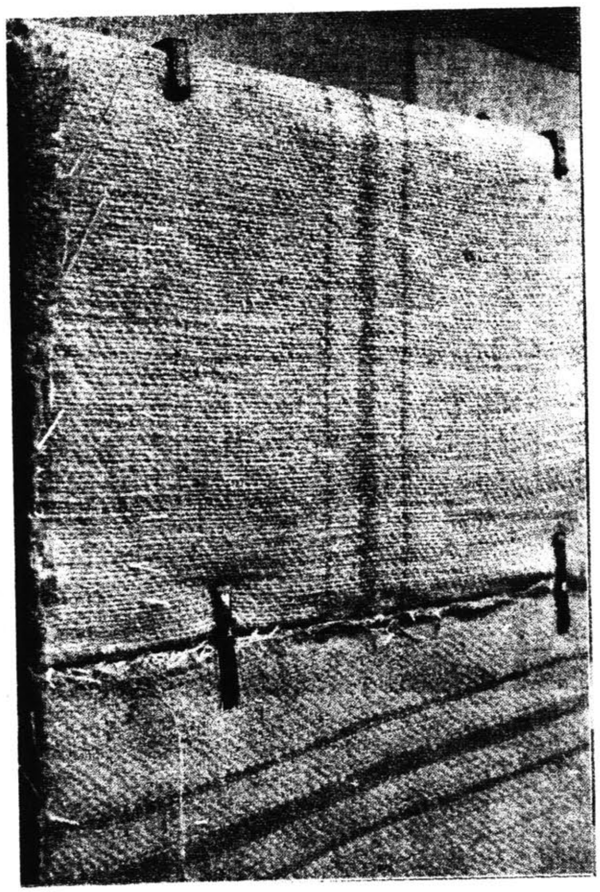


Figure 4-28. Jute faced straw boards fastened to masonry wall with metal brackets and masonry screws

In addition to the direct monetary benefits of the straw-MDI boards, there are two other significant advantages to this technique for developing regions: 1) the use of a local material as a substrate; and 2) use of local labor for fabrication. These two factors are crucial to the long-term success of any technology transfer to a developing country.

Although MDI is more costly per pound than the other binders, the binder efficiency is much higher and the board product is the least expensive per unit of thermal performance. Additional benefits are water and decay resistance. With the PVA, sodium silicate, and wheat flour, our research has generated more questions than it has answered as is the spirit of most scientific inquiry. With the MDI we were able to achieve all of our design objectives and have developed an optimized product to solve a real-world problem as is the spirit of most engineering. Additionally we were able to make significant advancements in understanding the impacts of fiber length concentrations and density on the thermal performance of cellulosic based insulation materials.

5. Board Fabrication Exploratory Research

This chapter was co-authored by Henry S. Harvey [1997] who collaborated on this research.

The material presented here is a summary of findings from the initial insulation board research. Three methods of board fabrication were explored:

1. using a combination of slight processing, such as shredding, soaking or heating, and adhesive binding;
2. mechanically containing the straw either in jute bags or in panels with wire and battens; and
3. pulping the straw to form a board.

5.1 Medium Processing with Binder

Initially we considered adhesives that are widely available in many regions. The logical thought was to use one of the natural glues made from plant and animal protein or starch. Certainly in a country with slaughterhouses, blood or collagen glue would be a possibility. In a country with a seasonal dairy surplus casein glue is a good idea. Pakistan produces wheat, and good adhesives can be made from any starch source, typically corn, wheat or potatoes. We have tried wheat flour.

A supplier of water based adhesives recommended PVA and sodium silicate. These seemed like good choices as they are both widely manufactured and relatively inexpensive. PVA has replaced animal glues for household use and is massively produced for many industrial applications including sprayed on insulation. Sodium silicate is of lower cost, and is representative of the inorganic adhesives. It also has a history of use in insulation materials such as asbestos, and is highly resistant to fire.

5.1.1 Experimental Techniques with Water Soluble Binders

For this segment of the research, we used both uncut oat straw as received in bales and shredded oat straw. Although wheat straw is the type that is common in northern Pakistan, oat straw is the only locally available straw type in the Boston vicinity. For shredding equipment, we used a small hammer-mill and a small yard mulcher at different times. We used it dry, and tried soaking it in water, ethanol, and solutions of sodium chloride and boric acid. Adhesives have been applied in various proportions, from 1 to 1, to 1/8 to 1, weight of wet adhesive to weight of dry straw. For the spraying process, we mixed the PVA, or the sodium silicate, with water and sprayed the solution onto the straw with a tank sprayer, while agitating the straw manually. In the case of foaming, the glue-water mixture was foamed by beating with an electric mixer after adding a small amount surfactant. The foam was folded into the straw like egg whites into a cake batter. Alternatively, we dipped the straw in solutions of PVA at various strengths.

Samples made by all of these methods had 4 oz. (113.5 grams) of straw and were put in square wooden molds eight inches on a side with a screen on the bottom. After drying the samples were weighed and thickness measured to find density. Mechanical properties were assessed qualitatively as good, fair, poor, or bad. "Good" means it has enough cohesion to work for our use. "Bad" means it cannot be picked up without crumbling.

With samples in the five lb/ft^3 to six lb/ft^3 density range, shredded straw works better than uncut straw. It is easier to apply the adhesive and to fill the mold with the smaller pieces. The uncut straw boards have some large voids, with average dimensions of roughly 1/4" (6 mm). These inhomogeneities will allow convective heat transfer within the board and will diminish the board's overall thermal performance. It can be expected that at higher densities the void volume problem related to the uncut straw lengths would not be as severe.

We obtained better cohesion, per unit adhesive applied, from PVA than from sodium silicate, however we may not have been using the proper technique with the inorganic material. Also since sodium silicate costs two thirds as much as PVA we could use more of it, and still have a cheaper product.

Whether on not the straw should be soaked prior to gluing depends entirely on the method of glue application. The straw takes up three to four times its weight in water after a brief immersion. Initially we believed that the wet straw might reduce penetration of adhesive into the straw stalks, leaving more on the surfaces where we thought we wanted it. As we progressed, we learned that MDI is thought to be so efficient because it does penetrate into more cellulose fiber. Perhaps when the straw is dry, the PVA emulsion may be drawn closer to the straw in the response to osmotic gradients. In this scenario, the water in the emulsion penetrates the dry straw, leaving the PVA on the surface of the fibers to bond with other pieces. If the straw is wet, the glue emulsion may fall away from the surfaces. Our tests were difficult to interpret on this point and no conclusion was drawn on this issue.

Spraying the straw with a hand-held sprayer is laborious, and it is hard to distribute the glue well. Rotating the material in a tumbler during spraying might help. We diluted the PVA and the sodium silicate in water, adding from one to ten times the weight of water, as compared to the adhesive received from the factory. If there is too small a quantity of water is added to the solution, there isn't enough vehicle to spread the glue over all the surfaces that must be reached; the straw is too dry, and the board doesn't hold together. If too much water is used, the excess solution runs off the straw when it is placed in the mold, carrying away the adhesive. For spraying or foaming dry straw, four ounces of glue-water mixture per ounce of straw is about right. For wet straw, a 1:1 or 2:1 solution to straw mass ratio is better.

A few drops of ordinary dish detergent made it possible to foam the PVA emulsion when it was diluted in two to four quantities of water by weight. Sodium silicate does not foam well with this surfactant. An electric beater needs to be applied for several minutes. We think foaming could be improved with 1) a faster beater, 2) a surfactant more suitable for the adhesive at hand, and 3) a foam stabilizer. The foam mixes readily into the straw; this is faster than spraying. Foaming reduces density of the final product, which is desirable for thermal properties. In one of our samples in particular, the foam reached a point where it "carried" the straw in a very low density mash or "straw-foam." The resulting sample had by far the lowest density, but was not cohesive. The detergent surfactant did not make the boards stronger per amount of glue. The results of these tests are tabulated in Table 5-1 and Table 5-2.

MIT ID number	ratio wet glue to dry straw	glue preparation (oz. glue/ water)	straw preparation	actual density lb/ft³	structure qualitative	estimated materials cost cents/R-ft²	glue load by mass when dry %
96323	.12/1 PVA (wire and batten)	sprayed	dry	6.4	fair	3.9	
96220	1/1 PVA	sprayed (4/4)	dry	5.6	good	9.4	23
96219	1/1 sod. sil.	sprayed (2/4)	dry	5.3	fair	6.3	25
96222	.5/1 PVA	sprayed (2/4)	soaked in water	5.2	fair	4.7	6
96221	.5/1 sod. sil.	sprayed (2/4)	soaked in water		bad		
96227	.5/1 PVA	foamed (2/8)	dry	4.2	fair	4.4	12
96226	.5/1 sod. sil.	sprayed (2/8)	dry	4.4	poor	3.2	16

Table 5-1. Summary of the boards made with whole straw stalks [Harvey 1997]

MIT ID number	ratio wet glue to dry straw	glue preparation (oz. glue/ water)	straw preparation	actual density lb/ft³	structure qualitative	estimated materials cost cents/R-ft²	glue load by mass when dry %
96229-A	.5/1 PVA	foamed (2/8)	dry	6.5	fair	5.5	18
96229-B	1/1 PVA	foamed (4/16)	dry	8.9	good	11	35
96301-A	.38/1 PVA	foamed surf. (1.5/16)	dry	5.5	fair	4	11
96301-B	.38/1 PVA	foamed surf. (1.5/8)	soaked in water	2.7	bad	2.6	
96311-A	.5/1 PVA	foamed surf. (2/4)	soaked in ethanol	7.6	good	high	16
96312	.25/1 PVA	foamed surf. (1/4)	soaked in ethanol	6.1	fair	high	5
96314-C	.25/1 PVA 10% ethanol	foamed (1/12/1.2)	dry	5	poor	6	

Table 5-2. Partial summary of the boards made with shredded straw [Harvey 1997]

One interesting result is a remarkable increase in structural integrity, for a given amount of glue, achieved by soaking the straw in 100% ethanol. Adding 10% ethanol to the PVA-water mix with no prior soaking however, did not work as well. Ethanol has a surface tension of about 23 dynes/cm compared to water at 73. Water and alcohol are completely miscible and the mixture has a surface tension between 23 and 73. Wetting is crucial in adhesives, as the vehicle has to wet the substrate to deposit the glue, and decreasing surface tension should allow greater wetting of the straw. The PVA solution wets the ethanol soaked straw very well, spreading over all surfaces, and the PVA is then dried rapidly. The water-ethanol mix evaporates faster than plain water, as shown by rapid drying of our samples.

To gain a better understanding of the bonding, we performed very small scale observations of several adhered pieces of straw. A light microscope was used to study the dried samples. These results were also difficult to interpret. The main comparison between the normal straw-PVA bonding and that of the alcohol soaked straw was an observation of glue drips versus a pattern of small glue bumps. With the sample of poorer bond strength, it appeared the glue had responded to gravity and dried with micro-drips hanging off parts of straw stalk into void areas where they are unable to contribute to board cohesion. With the better bound samples, the binder resembles raised micro-bumps that could possibly be acting to increase the surface area and the surface friction of the stalks. These observations are in the domain of qualitative speculation.

Also there is some interaction between the alcohol and the PVA, that we observed by dropping some PVA into pure ethanol. The alcohol appears to pull water rapidly out of the PVA emulsion, leaving a gummy solid behind.

We also tried dipping the straw into an aqueous solution of five percent, nine percent and 33% PVA concentration. In the first run we used dry straw, in the second run wet straw, and in the third run dry straw with a silicon wetting agent in the PVA solution. The samples were weighed wet, just after pressing as they came out of the bucket, as well as after drying. The 33% solution carried too much adhesive, producing a rock hard, expensive board. The five percent and nine percent solutions carried too little, or what was loaded didn't act efficiently. Soaking in water first didn't help much if at all.

Note that in all cases the weight of solution absorbed by the straw is greater as the mass percentage of PVA increases. Since the specific gravity of the PVA emulsion is about 1.15, this effect is much greater than can be accounted for by the greater density of the solutions. So an increased volume of solution is taken up as glue loading goes up. We would like to understand this effect, which could be related to viscosity, if the more viscous liquid is harder to press out of the straw.

5.1.2 Wheat Flour and Straw Panels

Whole wheat flour has proved to be a very effective binder in the ratio of 1 part flour to 2 parts straw. The boards that performed the best structurally were found to occur when the wet mixture was given a chance to begin the decomposition process. This process can immediately identified by the smell of rot and secondarily, upon visual inspection, it is easy to note the presence of a grayish mold on the nodes of the straw's surface. It appears as though this process is a form of natural pulping. The mold breaks down part of straw-flour mixture and grows a kind of web which fills in the interstitial spaces (void volumes) resulting in a more homogeneous end-product. The process used for these panels is as follows:

1. Mix dry straw and flour thoroughly before adding water
2. Add approx. 15 drops of Ajax dish detergent to water in the quantity of 3.5 times the straw weight, and spray onto the dry mixture, constantly rotating the straw to ensure equal coverage.
3. Lightly press in frame with wood board on top and approximately 0.14 psi, leave for 24 hours.
4. After 24 hours, remove top piece of wood and leave in the mold, place in front of fan until dry.

The negative aspects of this process are exactly the same as the positives. Mold is not something anyone would want to seal in his or her walls. Also the flour makes the panel nutrient rich and susceptible to rodent or pest attack. However, northern Pakistan is essentially an alpine desert terrain which receives very little rainfall each year. This suggests the flour-straw panel would be more suitable there than in most other climates.

5.1.3 Ash to Mitigate the Risk of Bioattack

Wood ash has been used for centuries as a low grade soil fertilizer and it is thought to act as a natural pesticide when applied to some plants. Its thermal conductivity is lower than that of straw. For these reasons it has been explored both as an additive to the straw boards and as a component of plaster materials. The addition of ash should improve the overall thermal conductivity of the panels may decrease the efficiency of some binders. Ash appears to retard mold growth but results in a panel which is less structurally sound than the pure wheat flour. In fact, the 1:2:4 proportion is not suitable for wall attachment due to the reduction in structural performance.

5.2 Mechanical Containment, Little Processing

5.2.1 Wire and Batten Method

We made a few samples of "wire and batten" boards. Strips of wood on each side of the straw panel were one inch wide (2.5 cm) and had a center to center spacing of 6 inches (15 cm). They were fastened to each other through the panel with wires. Uncut straw was oriented perpendicular to the battens. Sample size was two or three times longer than the average straw piece length. Doing this without the addition of a chemical binder didn't work at all. The sample came apart with a cleavage between and parallel to the battens, and would not support its own weight. We tried again using a small amount of binder, 1/8 to 1 by weight of PVA emulsion to straw. This worked reasonably well.

Similar straw panels were used to insulate buildings in Europe earlier in this century under the brand name Solomit [Hermannson 1993]. The panels were large (about 5 ft. by 10 ft. and 5 inches thick, or 1.5 m. by 3 m. by 120 mm.), with a density of 20 lb/ft^3 (320 kg/m^3) and an R per inch of 2 hr-ft^2-°F/Btu (0.07 W/m-K). They were held together with something like chicken wire and stucco plaster on the outside. They were treated against rot, but we do not know if they used any adhesive. Houses are currently being built from whole straw bales in this country, using various structural schemes, stuccoed on both sides. Density is around 8 pounds per cubic foot (128 kg/m^3) and R is about 3 per inch (0.05 W/m-K) across the grain.

We also tried containing the straw as a loose fill in both polyethylene and jute bags. This bag method is promising due to its low-technology nature and low cost potential. However because the bags are not rigid, it is difficult to apply a suitable surface finish. Plaster can be used with the addition of wood lath covering 75% of the surface area. The question remaining with this approach is how to avoid the additional surface finish costs?

An innovative technique was developed by which jute bags are sewn with three inch spacers strings were sewn through the bag at regular intervals. The straw was then sprayed with PVA and inserted into these bags. The final step was to press and dry the bags. The panels that were the most structurally sound used too much binder to be cost effective. The panels without excessive or any binder at all can be handled and fastened to walls however they have a bumpy surface geometry which is difficult to plaster. These panels were fastened to a concrete block wall using several low-cost methods:

1. masonry screws and jute string;
2. masonry screws with metal brackets;
3. string tied to wire loops that were fastened between the concrete blocks.

Pilot holes were drilled with a masonry drill bit where the masonry screws were used.

5.3 Maximal Processing: Pulping

5.3.1 Experimental Techniques with Sodium Hydroxide Pulping

Here we are breaking the straw fibers down, at least partially, and forming a board through a wet process. The board is primarily held together by hydrogen bonds between fibers, or by the natural adhesive properties of the released lignin; little or no extra adhesive is required.

We soaked two small (one-half ounce) samples of shredded straw (1/2" to 2" or 12 to 50 mm. length pieces) in a 4% aqueous solution of sodium hydroxide (NaOH-- caustic soda), for two and eighteen hours, respectively. The straw was dumped out onto a screen, pressed with a putty knife to squeeze out the caustic solution, which was reused, and the straw was left to dry under a fan. When dry, the samples are quite cohesive and have lost some mass, both effects being greater with longer soak time. When we repeated this with a 20% NaOH solution, we found greater cohesion and greater mass loss, again at two soak times. The longer soak time breaks the straw down more and gives a result similar to the stronger NaOH solution. These samples have considerable tensile and compressive strength, as much as needed for our purpose

Recovery of chemicals is necessary in any chemical pulping both to cut cost and to reduce environmental problems. The liquor accumulates dissolved or broken down straw parts, we think mostly lignin, so there is a definite limit to reuse. Commercial pulp mill recovery operations are energy intensive, as the spent liquor is boiled to produce steam and reduce the chemicals.

The major problem with this technique is that the sodium hydroxide appears to remain active in the board. Over time, the boards will most likely turn to dust. The remaining question is how to neutralize the strong base without degrading the relatively weak lignocellulosic bonds? Preliminary attempts of adding boric acid has resulted in a complete degradation of the important bonds. Boric acid is widely used as a fire prevention additive to loose-fill cellulose insulation. Future research could target mechanical pulping by grinding the straw in the hope of achieving a similar effect without chemicals.

5.3.2 History of Pulping

People have been soaking straw in caustic soda since the 1920's to make it more digestible for cows and sheep [Soltes 1983]. Apparently the cells swell up so much that the stiff outer lignin sheath is cast off, making the cellulose more accessible to enzymes and microorganisms. One article mentions that the straw can be made into blocks without binder because "NaOH acts as a binding agent in the presence of lignin.". It appears that the lignin can be thought of as a thermoplastic which can be softened either with heat or with a powerful base.

The North American insulation board industry pulps wood mechanically. They chip logs into 1/8" (3 mm) thick pieces, then defiberize them [Suchsland and Woodson 1987]. One method is the masonite gun, which steams the chips at moderate pressure, then explodes them by opening the port to the vessel suddenly. In another method the chips go to a disk refiner, in which they pass between two rotating grooved steel disks with a given clearance, on the order of a few hundredths of an inch (about one mm). The result in both cases is pulp in which the wood fibers or cells are nearly completely separated.

The pulp is watered down to a consistency of a few percent, and sized with asphalt (about 10% to weight of dry board) or wax (about one or two percent) [Suchsland and Woodson 1987]. The sizes are precipitated on the fibers by lowering the pH with aluminum sulfate; they make the board water repellent and have some binding properties. Starch (about one percent) may be added as an additional binder. The wet mat goes to a Fourdrinier machine with big rollers and long continuous screens, similar to those used in paper manufacture. Water drains through the screen and the boards are pressed and dried. The boards may have to be heated enough in a drier to make the asphalt flow.

Additional binders notwithstanding, the primary mechanism holding insulation fiberboard together is hydrogen bonding, according to Suchsland and Woodson [1987]. As the water evaporates, surface tension pulls fibers into intimate contact, within the range of attractive forces of surface hydrogen groups. This process yields a board with excellent mechanical and modest thermal properties. Density is around 20 lb/ft^3 (1.25 kg/m^3) and R/inch is 2.8 (0.05 W/m-K). We initially ruled it out because of the extensive water, energy, and equipment requirements.

Part II. Thermal Performance of Self-Help Schools in the Northern Areas and Chitral Pakistan

6. Report on Site Surveys

This chapter was co-authored with Dr. Jonathan Wright of Loughborough University, UK, who collaborated on the site survey.

6.1 Introduction

This chapter summarizes observations made on the thermal performance of community-built (self-help) schools in northern Pakistan. The purpose of visiting the schools was primarily to gather data for use in computer simulations. The simulations of the thermal performance of the schools are presented in next two chapters.

Four schools were studied during a visit to northern Pakistan in November 1995. There are two main building designs in the self-help schools of northern Pakistan. The two designs are referred to as pre-R&D and post-R&D. The names refer to a research project that was carried out several years ago to improve the structural and seismic performance of the buildings. The current study of building thermal performance covers three school designs and three wall constructions:

1. Pre-R&D design consisting of seven separate classroom blocks placed radially about a central core block. All of the buildings have a flat roof and walls constructed from hollow core concrete blockwork. The school of this type that was studied, was located at Danyore in the Gilgit valley.

2. Post-R&D design consisting of a four room building with a central corridor. The building is constructed with a flat roof and has hollow core concrete blockwork walls and roof. The school of this type that was studied, was located at Ahmedabad in the Hunza valley.

3. Four room post-R&D design constructed with semi-dressed stone or terracrete walls and a pitched corrugated galvanized iron roof. Two schools of this type were studied, Ghakuch in the upper Gilgit valley (semi-dressed stone) and Parvak in the upper Chitral valley (terracrete).

Although a fourth wall construction type exists using cast boulders, it has not been studied since only one school of this type exists at Uchu in the Chitral region.

Site surveys included collection of the following data:

- Site and school-construction information
- Schedule of school use
- Number of occupants
- Occupant survey, with questions about lighting and perceived thermal comfort
- Lighting measurements

- Measurements of leakage airflow into the schools, made with a calibrated fan mounted in doorways
- Measurements of thermal resistance of walls
- Measurements of density of wall materials
- Measurements of indoor and outdoor temperatures

6.2 Methods

6.2.1 Temperature

Temperature data was collected on-site with Onset Computer's HOBO® Temp type temperature loggers which are relatively inexpensive, very easy to use, and reliable.[10] Each logger unit has a thermistor sensor within the device casing to measure the ambient temperature. The thermal time constant (90% response to a step change in temperature) of a HOBO Temp's internal sensor within the casing is fifteen minutes in air. These devices are 6 cm tall, 5 cm wide, and 1.9 cm thick. They have a temperature range of -20°C to +70°C within a maximum error and resolution of one degree Celsius (Figure 6-1). Each unit can store 1800 data points and the time interval between measurements can be programmed via a computer software program. A time interval of 30 minutes between measurements was selected to accommodate the technicians who retrieved the data and reset the devices; this interval required them to visit the school every five weeks. Indoor and outdoor devices were left at two schools, Ahmedabad and Danyore, to provide long-term measurements of indoor and outdoor temperatures. The indoor devices were placed in classrooms out of direct sunlight on shelves at an approximate height of 1.7 meters and 15 centimeters out from the wall. The outdoor temperature devices were placed out of direct sunlight on the north side of buildings at approximately the same height and distance from the walls.

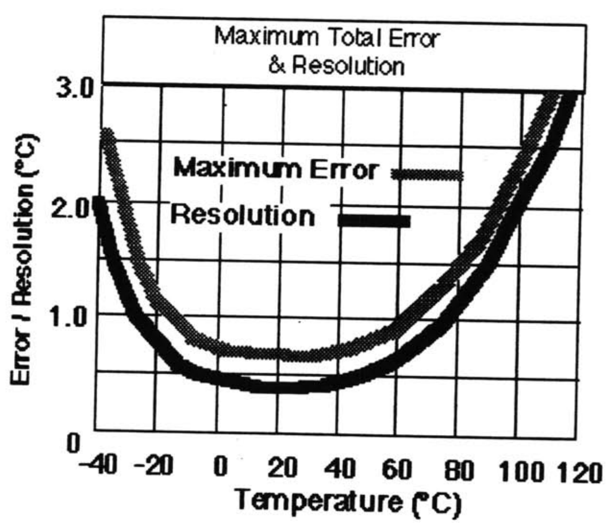


Figure 6-1. Error and resolution of the HOBO® Temp loggers [Onset Computer 1996].

[10] HOBO is a registered trademark of Onset Computer Corporation, Pocahasset, Massachusetts.

A different type of temperature data logger was installed in the Parvak school. When this unit was returned to us however, it did not contain any data. The unit had either lost all of its data or had not been properly launched.

6.2.2 Perceived Thermal Comfort

Occupancy surveys were used to assess levels of perceived thermal comfort, air quality and overall building performance for both the winter and summer months. Details and summaries of the occupancy surveys for each school can be found in Section 13.3.

6.2.3 Density

Mass and volume measurements were taken to compute the densities of the construction materials. The mass of the wall construction materials was measured using a simple scale. A measuring tape was used to measure the volume of the terracrete and hollow core concrete blocks. To facilitate the volume measurements of the irregularly shaped stone, the stone was submersed in a bucket of water and the volume was equal to the water displacement. Three representative samples of each material were measured for accuracy.

6.2.4 Thermal Conductivity

The thermal resistance of the materials was estimated by measuring the heat flux through the building fabric together with the corresponding temperature difference across the fabric. The thermal conductivities of the construction materials were measured using a heat flux meter, mercury bulb thermometers, chromega-constantin thermocouples, and heat sink compound. The heat flux instrumentation is composed of an OMEGA® HFS-4 thin film heat flux sensor and a DC-powered OMEGA® DP41 process meter.[11] The HFS sensor is a thin foil, differential thermocouple sensor with a 40 junction thermopile bonded to both sides of a Kapton barrier of known thermal characteristics [Omega 1994]. Since the temperature is known on both sides of a known thermal resistance, the exact rate of heat transfer can be calculated. The measurement could theoretically be made with only one junction on each side of the Kapton however the extra 39 junctions provide amplification of the signal. The HFS-4 has a sensitivity of 6.5 microVolts per Btu/ft^{2}Hr. It includes an integral Type K thermocouple and has two wires for heat flux measurement and two wires for the thermocouple hookup. The sensor has a nominal thickness of 0.009 inches and a response time of 0.70 seconds. The DP41 meter features 6-digit readout, is accurate to 0.005% of the reading, and has a range of ±50 milliVolts. It can be programmed to scale the output to display directly in Btu/ft^{2}Hr. The accuracy of the instrumentation was checked against the calculated output of the unguarded flat plate thermal conductivity tester (accuracy of ±5%). At steady state, the agreement was found to be within ten percent.

[11] OMEGA is a registered trademark of Omega Engineering, Incorporated.

In practice, measurements proved to be much more volatile. Accurate measurements rely on the building being in thermal steady state. Using this method to measure the thermal conductivity of construction materials is extremely difficult because steady state conditions with a temperature difference across the material are rare to nonexistent. The closest approximation to the ideal was to take readings as soon as I arrived in the morning from 8:30 AM to 10:00 AM. This schedule minimized the impact of solar radiation and internal sensible heating from the occupants. I would select an unoccupied room on the north side of the building. In this room I would attach the heat flux sensor to the north outside wall with thin polyester tape. A thin film of heat sink compound was applied to the Kapton to ensure good contact with the wall. When electricity was available, I used the Type K thermocouples with a separate meter to measure the inside and outside temperatures simultaneously. The outside thermocouples were sent through a window frame. The thermocouples were attached to wall with duct tape and heat sink compound to avoid measuring the temperature in the surface boundary layer. An attempt was made to match the exact location of the inside and outside temperature recordings. Where electricity was not available, glass mercury thermometers were used to measure wall temperatures. In this case duct tape and heat sink compound was also used. A minimum of four sets of temperature readings were taken for a given location of the heat flux sensor. The sensor was placed in a minimum of three different locations. The nature of heat flow measurement is that it is very sensitive to heat from the experimenter's hands and body as well as to heat from sunlight. Extreme deviations in the data were assumed to be the result of temporary heat fluxes and temperature changes, these extremes were discarded. In the remaining data, there was an average deviation of ±25% about the mean.

6.2.5 Natural Infiltration

A Minneapolis Blower Door was used to estimate the air leakage area of these buildings in the field. In this technique a fan is placed in a doorway of a building and is used to either pressurize or de-pressurize the building. Multi-point pressurizing tests were run at every school except for Danyore where electric power was insufficient on the date of the survey. Indeed we had a portable 750 Watt gasoline powered electric generator at Danyore, but at least 1 Kilowatt of power was required to run the Blower Door fan. In Ahmedabad, sufficient power could only be achieved by placing the generator in a parallel circuit with the line voltage at the school supplied by a local hydroelectric generator. The fan pressure and house pressure were recorded at a minimum of three different points. At both the Ahmedabad and Parvak schools, two sets of measurements were taken. The first set measured the schools in the original condition. Then the double-doors and windows at one end of the corridor were weatherized. The edges of the door and the window frames were lined with foam tape and extruded vinyl weatherstrip was applied to the bottoms of the doors. After this procedure, a second set of fan measurements were taken.

A standard measure of the air tightness of a building is the airflow at a 50 Pascal pressure difference between the inside and outside of the building (Q_{50}). When a 50 Pascal pressure differential is not able to be achieved as was the case in all three schools, a scaling factor can be used to estimate the Q_{50} based on the airflow at the highest achievable pressure [Energy Conservatory 1996]:

$$Q_{50} = Q_{max} * (50/P_{max})0.65 \qquad \textit{Equation 6.1}$$

where,

P_{max} = maximum achievable pressure, Pascal; and
Q_{max} = maximum achievable airflow, ft^3/minute.

A correlation between air velocity through the fan and the pressure difference across the building envelope is used to derive a value for the effective leakage area (*L*) of the building [Energy Conservatory 1996]:

$$L = Q * 0.2835 \qquad \textit{Equation 6.2}$$

where,

L = effective leakage area at a desired pressure difference, $inches^2$; and
Q = airflow at a desired pressure difference, ft^3/minute.

The effective leakage area can also be estimated by adding up the table leakage values for the individual building components. ASHRAE describes an equation based on work performed at Lawrence Berkeley Laboratory for calculating air infiltration rates of single-zone residential buildings [ASHRAE 1989, section 23.17, equation 33]. The equation for the airflow rate due to infiltration is:

$$Q = L(A\, \Delta T + B\, v^2)^{1/2} \qquad \textit{Equation 6.3}$$

where,

Q = airflow rate, ft^3/minute
L = effective leakage area at a pressure of 0.016 inches water, $inches^2$
A = stack coefficient, $(feet^3/minute)^2(inches)^{-4}(°F)^{-1}$
ΔT = average indoor-outdoor temperature difference for the time interval of calculation, °F
B = wind coefficient, $(feet^3/minute)^2(inches)^{-4}(miles/hour)^{-2}$
v = average wind speed measured at a local weather station for the time interval of interest, miles/hour (mph)

The infiltration rate *I* in air changes per hour (ACH) is given by dividing the airflow rate per hour by the volume of the building:

$$I = (Q/Volume) * (60\ minutes/hour) \qquad \textit{Equation 6.4}$$

The value of the wind coefficient *B* depends on the local shielding class of the building and the building height. The shielding class describes the magnitude of obstructions surrounding the building. The stack coefficient *A* depends on the height of the building and the distribution of leakage area between the floor, walls, and ceilings. The airflow at four Pascal (0.016 inches water) is required for Equation 6.3. Although the airflow at four Pascal is too low to accurately measure with a Blower Door, it can be derived from the airflow at 50 Pa using the same general equation as Equation 6.1 [Energy Conservatory 1996]:

$$Q_{4Pa} = Q50 * (4/50)^{0.65} \qquad \textit{Equation 6.5}$$

Then combining Equations 6.5 and 6.2, the effective leakage area at 4 Pa is given by:

$$L_{4Pa} = Q_{4Pa} * 0.2835 \qquad \textit{Equation 6.6}$$

6.3 Data Collection and Survey of the Schools

6.3.1 Danyore

Date of survey: 19th and 20th November 1995.

Location: Danyore is located in the Gilgit valley (running approximately east-west). The school is generally unobstructed from surrounding buildings or hills (Table 6-1). The location ensures that the school is subject to solar gain throughout the year; this is particularly intense in summer when the sun passes approximately overhead. Wind velocities are reported to be low (less than 1.0 m/s) so that infiltration is primarily due to the difference in air density between the inside and the outside of the building (buoyancy driven airflow).

Building type and construction: The Danyore school is a pre-R&D design consisting of seven separate classroom blocks placed radially about a central core block (Figure 6-2). All buildings have a flat roof and walls constructed from hollow core concrete blockwork. The walls are reinforced with steel bars placed horizontally between every third layer of blockwork. Vertical reinforcing has been placed in every third hollow core and the core filled with concrete (ratio 1:2:4, cement:sand:aggregate). The floors are of a solid concrete construction (Table 6-9).

The roof is constructed from hollow core concrete slabs 152 mm deep by 304 mm wide. Each slab has two 76 mm diameter hollow cores. The roof slabs are placed between reinforced concrete beams 450 mm deep by 200 mm wide. The beams are placed on 1.83 m centers (giving four in each classroom). The corridors formed between the buildings also have hollow core concrete slab roofs, with the exception of the corner junctions where the roof is constructed from timber; the whole roof is covered with a 50 mm layer of mud.

The connecting corner walls between each building are also constructed from timber and single glazed windows. Windows in the classrooms are double glazed (Figure 6-2). Every corridor and classroom has a skylight (Figure 6-3).

Building operation: The school is in use from February to June and August to December and is occupied six days a week between 8:15 am and 2:15 pm. Six hundred pupils attend the school daily with an average of forty-five occupying a classroom at any one time. The high number of pupils has also led to the corridors being used for teaching. Extra lessons may also given between 2:15 p.m. and 5:00 pm

No heating was available in the school, although it was reported that in very cold winters, wood burning stoves would be used during November and December (smoke stains around roof holes used to install the stove flues suggested that stoves had been used in the past). Due to the shortage of fuel, which is provided by the pupils, the school may close and the semester dates be changed, if the weather becomes too cold for the building to be used. Although no stoves were in use, many of the classes were being taken outside where the solar radiation made it feel considerably warmer. The school is considered to be too hot between of May and September.

Electricity is available intermittently and is used for background lighting (no electricity was available during the two days of the survey).

The doors and windows of the buildings are closed at night throughout the year.

Maintenance: Although the structural elements of the buildings are in good repair, most timber elements have not been maintained. The window frames fit loosely as do the skylight frames. The glass in many skylights has slipped down by up to 75 mm to leave large gaps, allowing infiltration. Some of the glass in the skylights is also cracked, which presents considerable danger to the occupants.

The unused roof holes provided for the stove flues were unplugged and as such are a potential source of infiltration.

Thermal performance: The large scale of the school leads to variations in thermal performance between the different rooms of the school. Room 2 (Figure 6-2), on the northern side of the school, is reported to be the coldest in winter, whereas the southwest facing rooms 9 and 10 are reported to be the hottest in summer. This is supported by temperature measurements taken during the survey. The location of the temperature units is shown in Figure 6-2. A pre-existing temperature monitor and sensor had been previously installed in room 10. The northern room 2 remained at a near constant temperature of 13.5 °C (Figure 6-4), whereas the temperature of the southwest room 10 was higher and varied between 14.5 °C and 15.5 °C. The surface temperatures of the walls in room 2 also remained constant whereas those in room 10 exhibited the effects of solar gain (Figure 6-4).

Room 4 in the northeast corner of the school was reported to be the coolest in summer; this was not just due to its position, which limits solar gain, but also due to the effect of cross-flow ventilation resulting from there being windows on both sides of the room.

It was reported that the room surfaces appear to be unusually cold during winter, which will give rise to poor thermal comfort (through radiant heat exchange). The low surface temperatures are partly due to the poor thermal resistance of the walls, roof, and floors. The thermal resistance of the walls is approximately 0.33 m^2K/W (Hollow Core Concrete Blockwork, page 109). This could be increased to approximately 0.91 m^2 K/W by adding a 20 mm layer of expanded polystyrene and a 10 mm plaster finish to the internal surface. This would give a potential reduction in heat loss through the external walls of 64% and lead to higher surface temperatures (the total energy saving would be lower since the heat loss through the windows, roof, and through infiltration would remain the same). The floors would also benefit from insulation, although the insulation would have to be robust and need minimal maintenance. However, insulating all the internal surfaces would limit the extent to which the building could be passively cooled by cold night air during the summer months. Therefore, it may be an advantage to leave the internal walls and the roof slab uninsulated so that these surfaces could be cooled at night and subsequently act as heat sinks during the day. The trade-off between insulating against heat loss in winter and allowing passive cooling in summer will be investigated as part of the computer simulation study.

The poor maintenance of the timber construction and roof lights may result in excessively high infiltration rates. Although high ventilation rates may be required when the school is occupied, it is important to be able to control the ventilation rates. In winter, for instance, heating requirements could be reduced by ensuring that the building was sealed at night so that the extent to which it would be cooled by infiltration of the cold night air is minimized. The potentially high infiltration rates may result in excessive cooling of the schools overnight during winter. In contrast, the infiltration rate appears to be insufficient for passive cooling of the building during the cool summer nights, and as such the school would benefit from an increase in ventilation during this period. This can be facilitated by opening the windows during the summer nights (although this may present a security problem).

Summer overheating could also be reduced by shading the windows on the southern and western faces. Considering that the sun has a high altitude in summer, shading the whole of the roof area may also reduce solar gain.

Light levels are reported often to be too low. This is supported by the measurements taken in room 11 (Figure 6-4), where the light intensity was below 100 lux (the minimum level for background lighting).

Orientation (Magnetic)		Elevation	Obstruction
	50°	28°	
	70°	19°	
(E)	90°	18°	
	110°	17°	
	130°	15°	Boundary wall
	150°	25°	Adjacent building
	170°	27°	
(S)	180°	28°	
	200°	25°	
	220°	24°	
	240°	19°	
(W)	270°	20°	
	290°	30°	
	310°	26°	

Note: the skyline profile was taken around the composite boundary of all the classroom blocks.

Table 6-1. Approximate Skyline Profile for Danyore

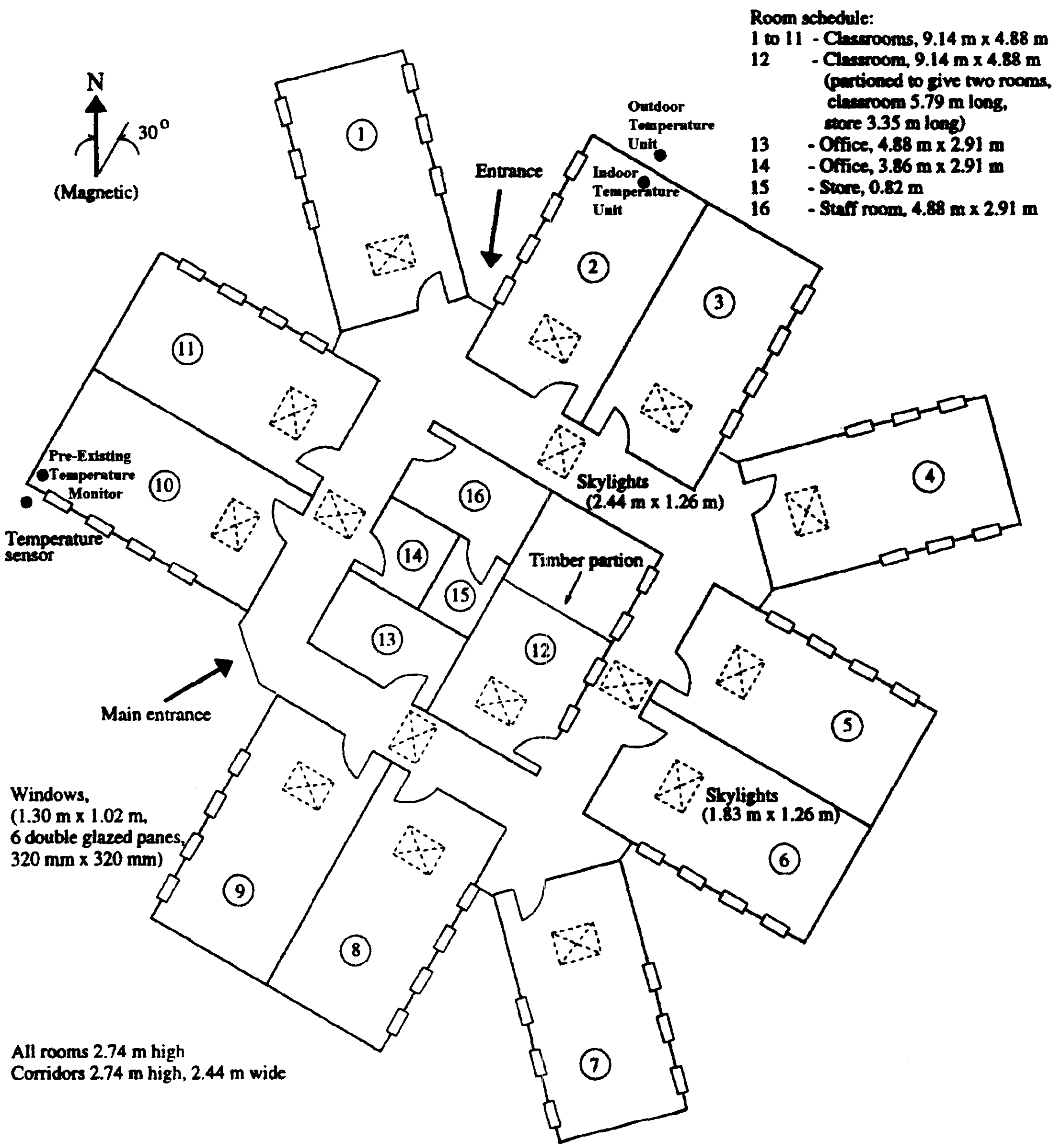


Figure 6-2. Orientation of Danyore

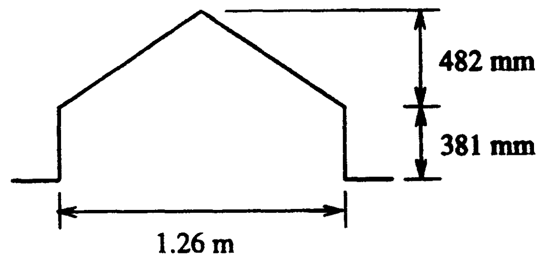


Figure 6-3. Skylight detail for Danyore

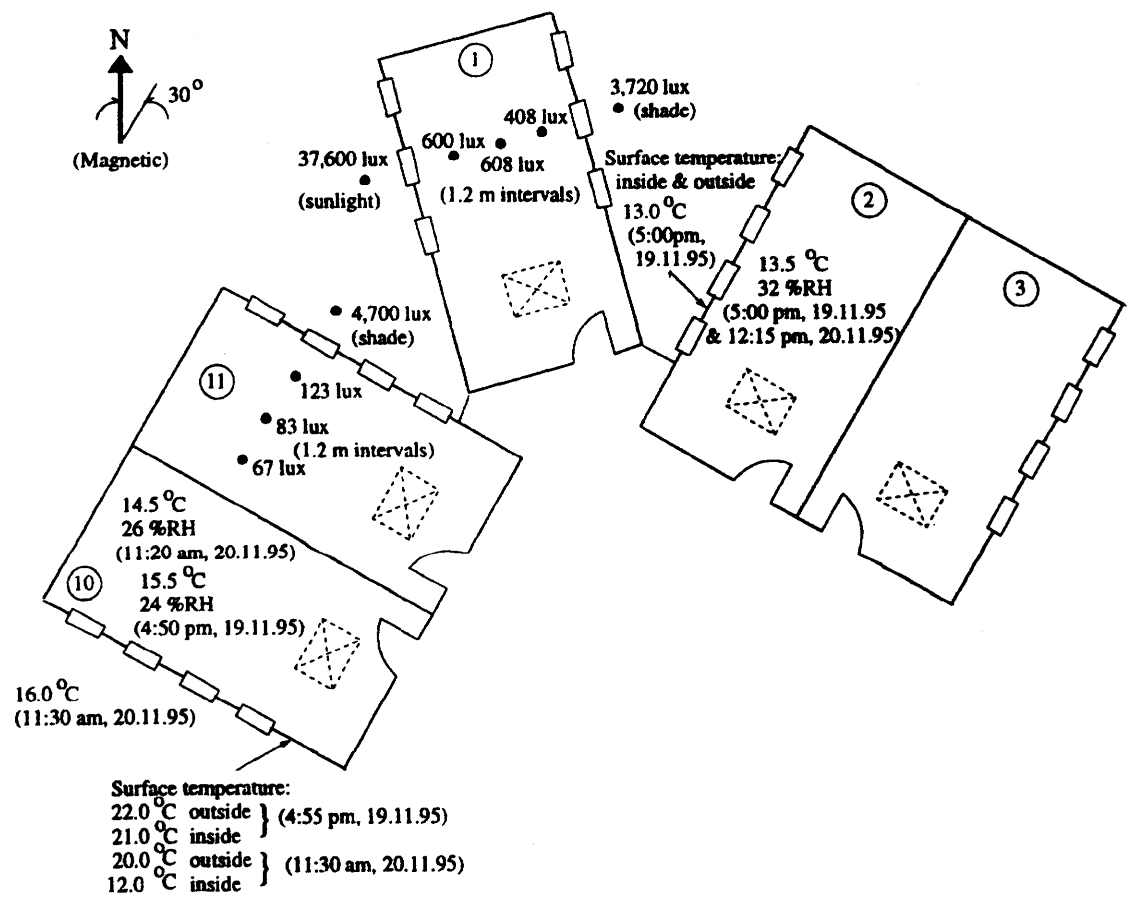


Figure 6-4. Temperature and light levels for Danyore.

6.3.2 Ahmedabad

Date of survey: 21" November 1995.

Location: Ahmedabad is located in the Hunza valley (running approximately east-west in the region of the school). There are currently two buildings on the site with a third under construction. The building surveyed was the north building (the second building is located adjacent to, and 3.66 m south of, the study building). The school is generally unobstructed by the surrounding hills, although the southern facade of the study building was shaded by the adjacent building (Figure 6-5). The site is subject to solar gain throughout the year although it was reported that there is often up to 35% cloud cover, and that between October and February this could often increase to 100%. Wind velocities are high enough make the ingress of dust into the buildings a problem, which would suggest that infiltration due to wind effect is significant.

Building type and construction: The Ahmedabad school is of a post-R&D design consisting of four rooms with a central corridor (Figure 6-5). The building has hollow core concrete blockwork walls that are reinforced with horizontal ring beams at a level below and above the windows, at roof level and at ground level. The ring beams are constructed from "U" shaped lintel blocks (manufactured from hollow core concrete blockwork). The "U" of the lintel blocks hold two steel reinforcing bars that are held in place with concrete. Vertical reinforcing bars have been placed in every fourth hollow core and the core filled with concrete. The floors are of a solid concrete construction.

The building has a flat roof which is constructed from hollow concrete blockwork placed between reinforced concrete "T" beams placed at 457 mm centers. The concrete blockwork is covered with 50 mm of screed and sealed with a layer of felt and tar (bitumen).

Each classroom has two skylights, although no skylights have been placed above the central corridor. The skylights are raised above the roof level and covered with a transparent corrugated glass fiber sheet (Figure 6-6). The entrance to the building (approximately 3.35 m x 2.44 m) is glazed with single pane windows, except for the unglazed doors (approximately 1.46 m x 2.10 m) and two wooden panels placed either side of the door at ground level (approximately 850 mm x 490 mm). All windows in the classrooms are double glazed (Figure 6-5).

Building operation: The school is in use all year, except during July and between the middle of December and the middle of February. The school is occupied six days a week from 8:00 am to 2:00 pm. Two hundred and nine pupils attend the school daily with between 30 and 40 pupils occupying each classroom.

During the survey, the classrooms were heated by wood burning stoves lit with fuel provided by the pupils on their arrival at school (wood for fuel was reported to be in good supply). All classes were being conducted within the classrooms. Electricity is available intermittently; during the survey, it was being used to power three 100 W incandescent lamps in each classroom, although the voltage was low enough for their output to appear to be that of a much less powerful lamp.

The doors and windows of the building are closed at night. Dust ingress into the building during high wind velocities may also lead to the doors and windows being closed during the occupied periods.

Maintenance: The building was in good repair, although the doors and windows did not close tightly, which will lead to high infiltration rates. In rooms that did not have stoves, the unused flue holes were not sealed.

Thermal performance: The school was reported to be too cold for at least three months of the year (between mid-November and mid-February). This was reported to be the case on the day of the survey and is supported by the air temperatures measured in the classrooms. By 10:55 am the north classroom was at a temperature of 12.0 °C while the external temperature was at 8.0 °C (Figure 6-7). The heat from the wood burning stove and the occupants had therefore done very little to increase the temperature of the room. The stove had been allowed to burn out thus discounting any further increase in temperature. The ineffectiveness of the stove can be attributed to the exposed mass of the building fabric which will tend to absorb the heat rather than allow the heat to increase the air temperature. On windy days, the high infiltration rate would be higher, which would result in even lower room temperatures. The south classroom had a higher temperature of 15.0 °C which may be due to the higher number of occupants and solar gain, although the southern facade is partially shaded by the adjacent building (Table 6-2).

As reported for the Danyore school, the concrete surfaces appear to be cold, which is due to the poor thermal insulation of the building fabric. Insulation of the external walls would improve the thermal performance of the building and feeling of thermal comfort. This also applies to the roof since its thermal resistance is poor and similar to that of the blockwork walls (Flat Roof, page 110). However, the thermal insulation of the building must be selected to give good thermal performance of the building during both winter and summer.

The school was reported to be too hot for only one month of the year (July). This suggests that solar gain during the summer is not too great a problem at this location. Similarly to the Danyore school, summer overheating could be limited by the use of cold night air to cool the building, although the reported migration of dust into the building may limit the applicability of this approach.

On average, it was considered that the light levels in the rooms were acceptable. However, during the survey the measured light levels in the north classroom were too low to be effective (Figure 6-7). The effect of the artificial lighting was negligible (partly due to the low electrical voltage supply). It was also reported that glare from sunlight entering through the windows can be a problem; this was confirmed during the survey were light levels of 1,450 lux where measured close to a window (Figure 6-7).

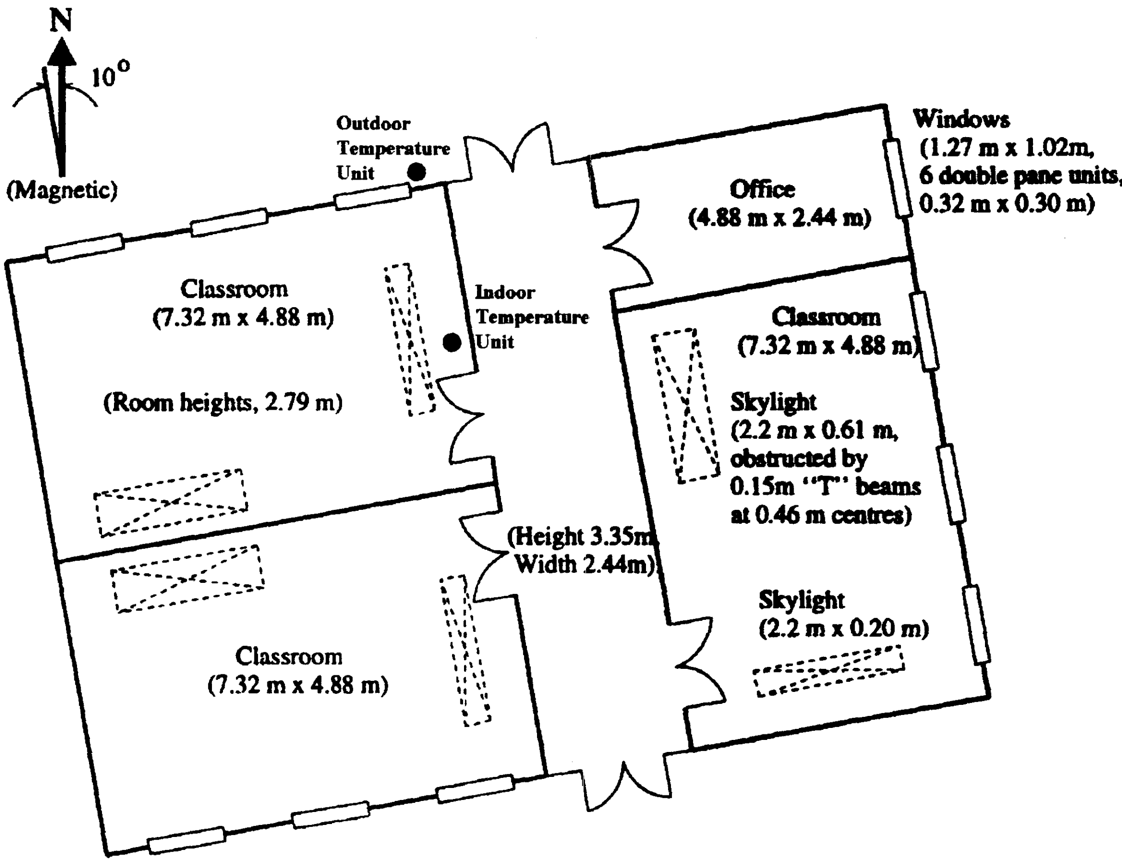


Figure 6-5. Orientation of Ahmedabad

Orientation (Magnetic)	Elevation[1]	Elevation for study (northern) building[2]
30°	35°	
60°	38°	
(E) 90°	21°	
120°	26°	
150°	28°	33°
(S) 180°	23°	34°
210°	25°	33°
240°	18°	
(W) 270°	30°	
300°	31°	
330°	36°	

1. The skyline profile was taken around the composite boundary of the two existing buildings.
2. South elevations for the study building were estimated from the 3.66 m distance between the buildings.

Table 6-2. Approximate skyline profile for Ahmedabad

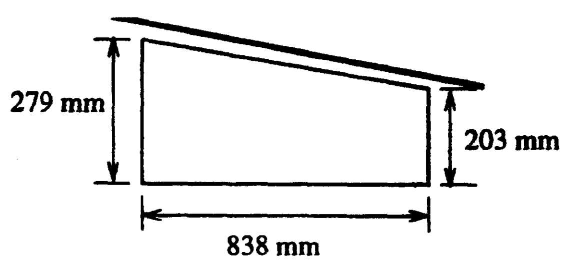


Figure 6-6. Skylight detail for Ahmedabad

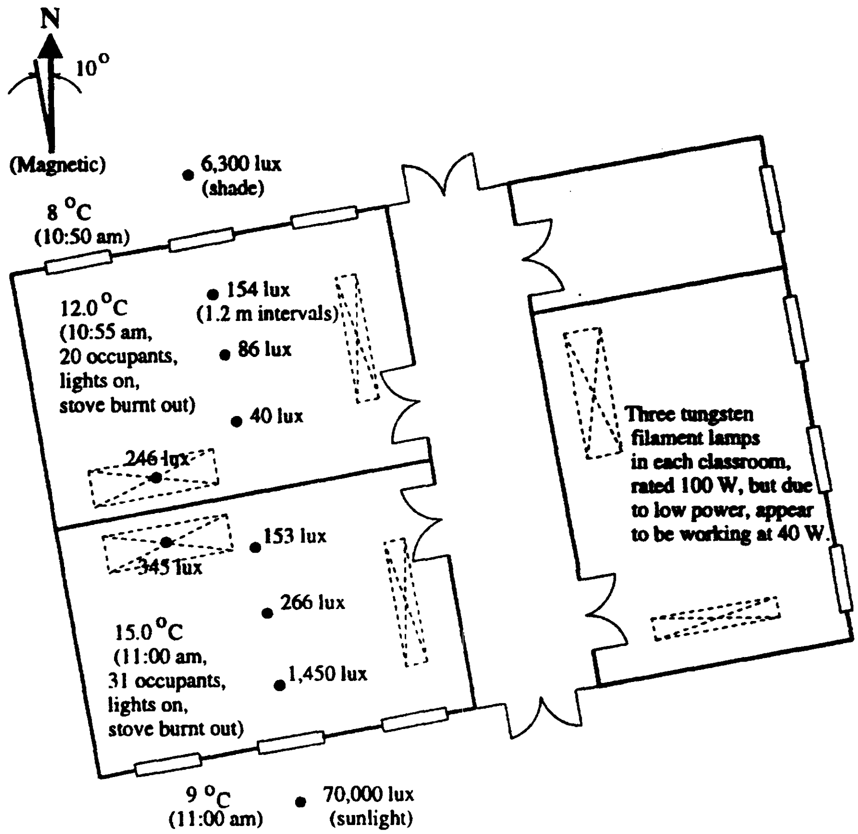


Figure 6-7. Temperature and light levels for Ahmedabad.

6.3.3 Ghakuch

Date of survey: 23rd November 1995.

Location: Ghakuch is located in the upper Gilgit valleys between Gilgit and Chitral. Two buildings are located on the site, only one of which is complete. The survey concentrated on the completed south building. The building is shaded on the southern and western facades by a boundary wall and trees (Table 6-3). The effect of shading during winter months is reduced since the trees shed their leaves. Twenty-five to thirty percent cloud cover is common. Occasional high wind velocities are experienced at the site. The velocity can be high enough to blow down trees. Significant wind driven infiltration is therefore likely to occur occasionally.

Building type and construction: The Ghakuch school is a post-R&D school consisting of four classrooms off a central corridor (Figure 6-8). The walls are constructed from 381 mm thick semi-dressed stone (granite), and the floors from solid concrete. The building has a pitched roof constructed from corrugated galvanized sheet steel, grass insulation and a plywood ceiling wall (Pitched Roof, page 110).

Each classroom has one skylight, and the central corridor two. The skylights fit flush with the pitch of the roof and are constructed from transparent corrugated glass fiber sheet. The entrance to the school is the same as for the Ahmedabad school. All windows in the classrooms are double glazed.

Building operation: The school is occupied six days a week from 7:00 am to 1:30 pm in summer and 8:30 am to 2:00 pm in winter. The school is used occasionally for meetings outside of the normal school hours. Two hundred and six pupils attend the school daily with an average of twenty five pupils to a. classroom at any one time. The corridor is sometime used for classes.

No heating was available during the survey, although new wood burning stoves were about to be installed. When in use, the stoves may be lit up to half an hour before school starts and fuel may be added up to the end of school if available, (the fuel is provided by the pupils and may not be available every day). Lessons were being conducted in the school during the survey, although some classes were also being taken outside.

Electricity is not available at the school (light fittings and power sockets have been provided for future use). The doors and windows of the school are closed at night.

Maintenance: The building was in good repair, although the doors and windows did not to close tightly, which will lead to high infiltration rates. The unused holes for the stove flues were not sealed. The roof construction and flush fitting skylights should need minimal maintenance in comparison to the flat roof designs (Danyore and Ahmedabad).

Thermal performance: The building is reported to be generally too cold during December and January, although some staff felt that the wood burning stoves, when in use, provided enough heat to make the classrooms comfortable. The effectiveness of the stoves is limited by the poor thermal resistance of the stone walls (Semidressed Stone - Granite, page 110), which will result in a high rate of heat loss. However, the roof is well insulated, having a thermal resistance of over twice that which could be achieved through insulating the walls with expanded polystyrene board and plaster, 0.86 m^2K/W for insulated walls and 2.23 m^2K/W for the existing roof (Pitched Roof, page 110). The high thermal resistance of the roof will result in a higher ceiling temperature which will improve the feeling of thermal comfort (it was reported that the room surfaces were generally not perceived as being cold). In comparison to the walls and the concrete floor, the roof has a low thermal capacitance and will not absorb excessive amounts of heat. This will minimize the time required to heat the building to a comfortable temperature.

It was reported that during the summer, the school building was not too hot and was cooler than the local houses. This may be due to the effect of shading of the southern and western facades of the building (Table 6-3). The reflectivity of the corrugated galvanized roof may also limit the solar gain through the roof.

As suggested for the Danyore school, the thermal insulation of the building must be selected to give good thermal performance of the building during both winter and summer. The low thermal capacitance of the roof suggests that further insulation of the building requires careful design, if the ability to passively cool the building during summer is not to be restricted.

During the survey, the light levels in the classrooms were generally acceptable. However, the levels in the northern classroom were a little low, whereas high levels of glare were apparent near to windows in the southern classroom (Figure 6-9). The flush fitting glass fiber skylights appeared to provided reasonable light levels and give an aesthetically appealing quality to the light, although it was reported that this was not always the case.

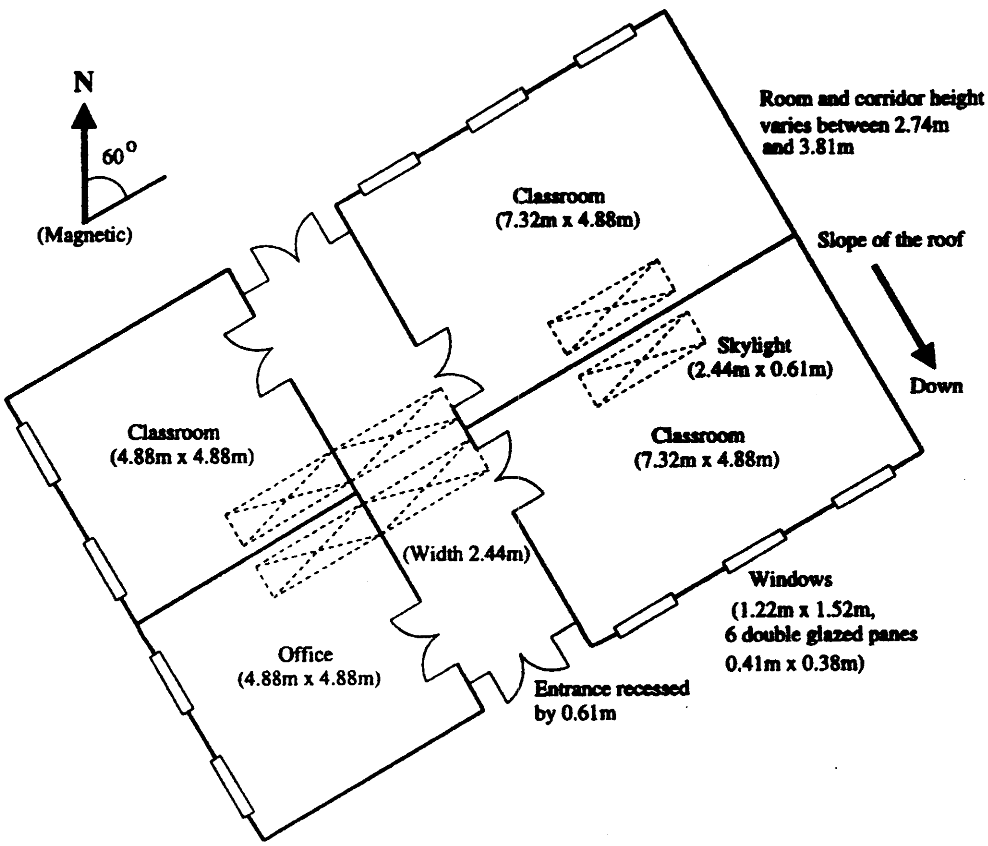


Figure 6-8. Orientation of Ghakuch

Orientation (Magnetic)	Elevation	Obstruction
30°	27°	
60°	21°	
(E) 90°	13°	Tree elevation 49°
120°	30°	Tree elevation 62°
150°	29°	Tree elevation 58°
(S) 180°	35°	Boundary wall
210°	35°	Boundary wall
240°	52°	Large tree
(W) 270°	25°	Boundary wall
300°	65°	Adjacent building
330°	16°	

Table 6-3. Approximate skyline profile for Ghakuch

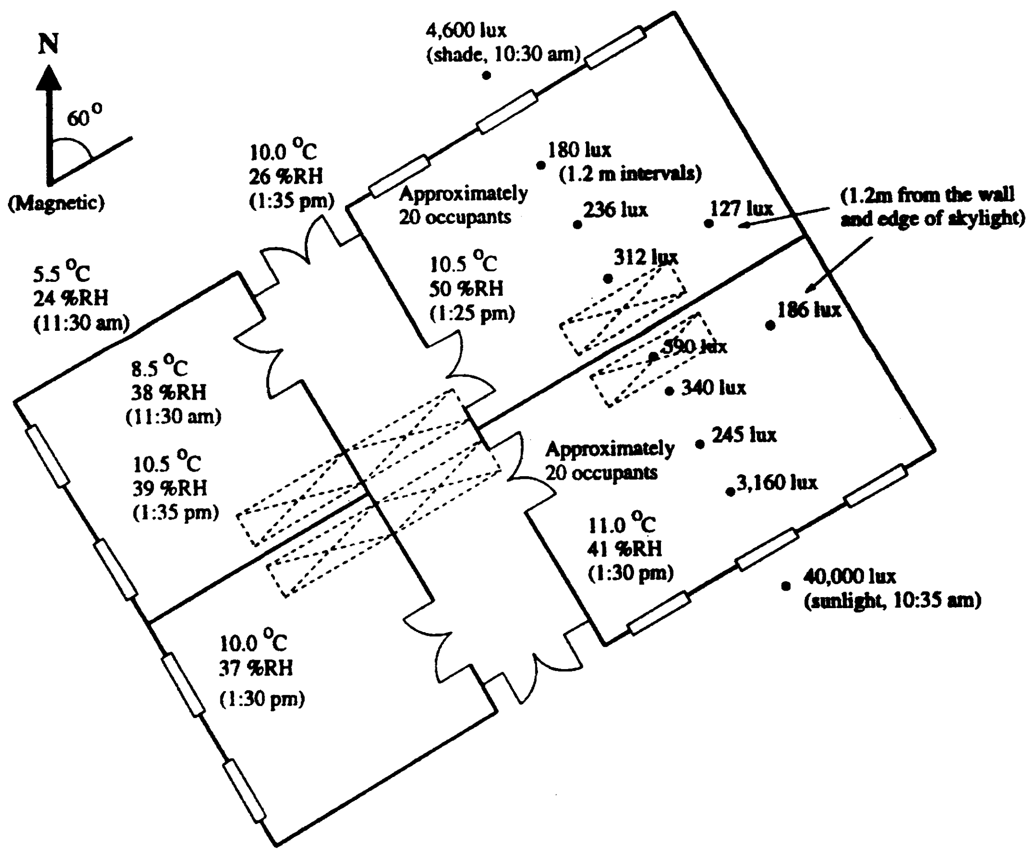


Figure 6-9. Temperature and light levels for Ghakuch

6.3.4 Parvak

Date of survey: 25th November 1995.

Location: The Parvak school is located in the upper Chitral valley (which runs approximately east-west). Two buildings are located on the site; the building studied during the survey was the more recent east building. The building is largely unobstructed other than being shaded on the western facade from the adjacent building (Table 6-4). The predominant wind direction is east-west, along which the central corridor of the building is aligned (giving potential for infiltration).

Building operation: The school is in use from March to June and from August to December. It is occupied six days a week from 8:30 am to 2:30 pm. Two hundred and sixteen pupils attend the school with an average of thirty five pupils occupying each classroom. No stoves were available in the building (no holes had been provided for stove flues either). Stoves will be fitted and will burn wood provided by the pupils, however wood is regularly unavailable for use in the school. The building was unoccupied during the survey with lessons being given outside; this was due to both it being warmer outside, and to facilitate the survey. No electricity is available at the school. The doors and windows of the school are closed at night.

Building type and construction: The building is of the same design and construction as the Ghakuch school, except that the walls are constructed from 300 mm thick terracrete blocks (Terracrete, page 110). The two smaller classrooms have been converted into one larger classroom and a small office (Figure 6-10).

Maintenance: In general the school was in good order, however the timber doors and windows did not close tightly. In particular, a large gap at the bottom of the entrance doors was apparent. The pitch roof construction and flush fitting skylights should prove to require minimal maintenance. It was noted that the cast insitu terracrete construction of the west building was badly finished and in need of repair in places.

Thermal performance: It was reported that the building was cold between November and March, and that some staff perceived the walls to be cold. This may be due to the terracrete having a high thermal capacitance which will limit the rate at which the classrooms can be heated to a comfortable temperature. The high thermal capacitance is indicated by the surface temperatures of the south wall, measured after the sun had heated the wall all day (Figure 6-11); since the thermal resistance of terracrete is low, the 9 °C temperature difference is probably due to a high thermal capacitance. As for the Ghakuch school, the roof has a high thermal resistance that limits the heat loss.

The school was reported to be cooler than local houses during the summer, but still too warm to be comfortable. The high thermal capacitance of the terracrete could be an advantage during the summer in that it will tend to absorb heat during the day limiting the increase in classroom temperature. Insulation of the walls against heat loss during the winter must be such as to ensure thermal performance during summer does not suffer.

The skylights where generally thought to provide enough daylight, although the windows often produced glare. The measured light levels were acceptable during the survey (Figure 6-11).

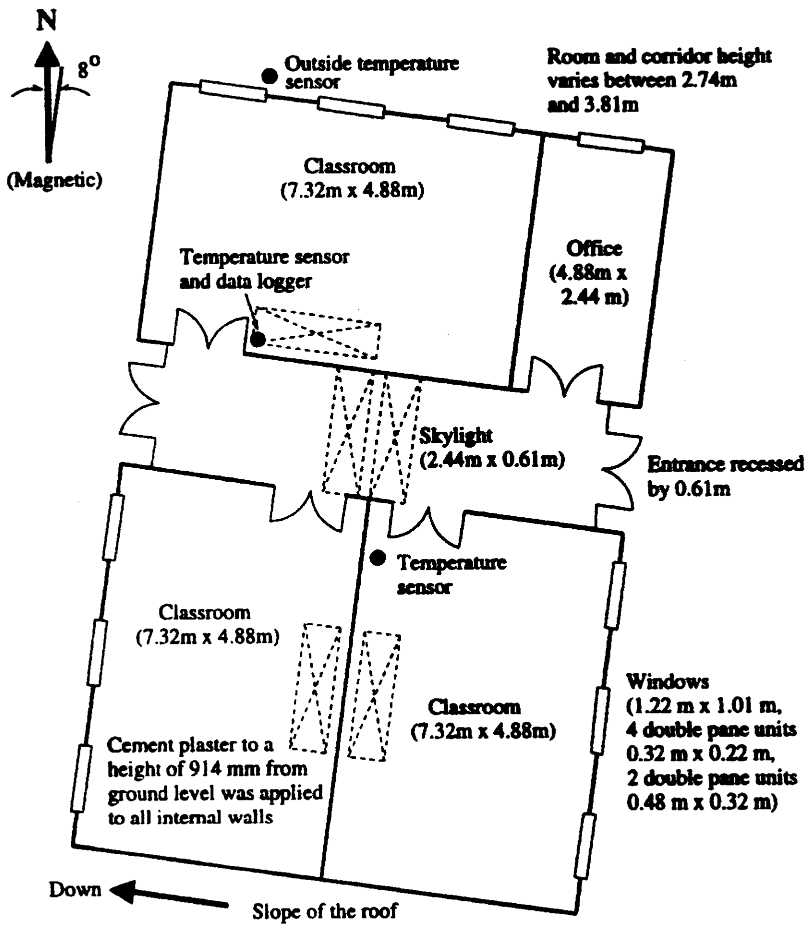


Figure 6-10. Orientation of Parvak

Orientation (Magnetic)		Elevation	Obstruction
	60°	14°	
(E)	90°	23°	
	120°	29°	
	150°	37°	
(S)	180°	35°	
	210°	33°	
	240°	28°	
(W)	270°	38°	Adjacent building
	300°	35°	Adjacent building

Table 6-4. Approximate skyline profile for Parvak

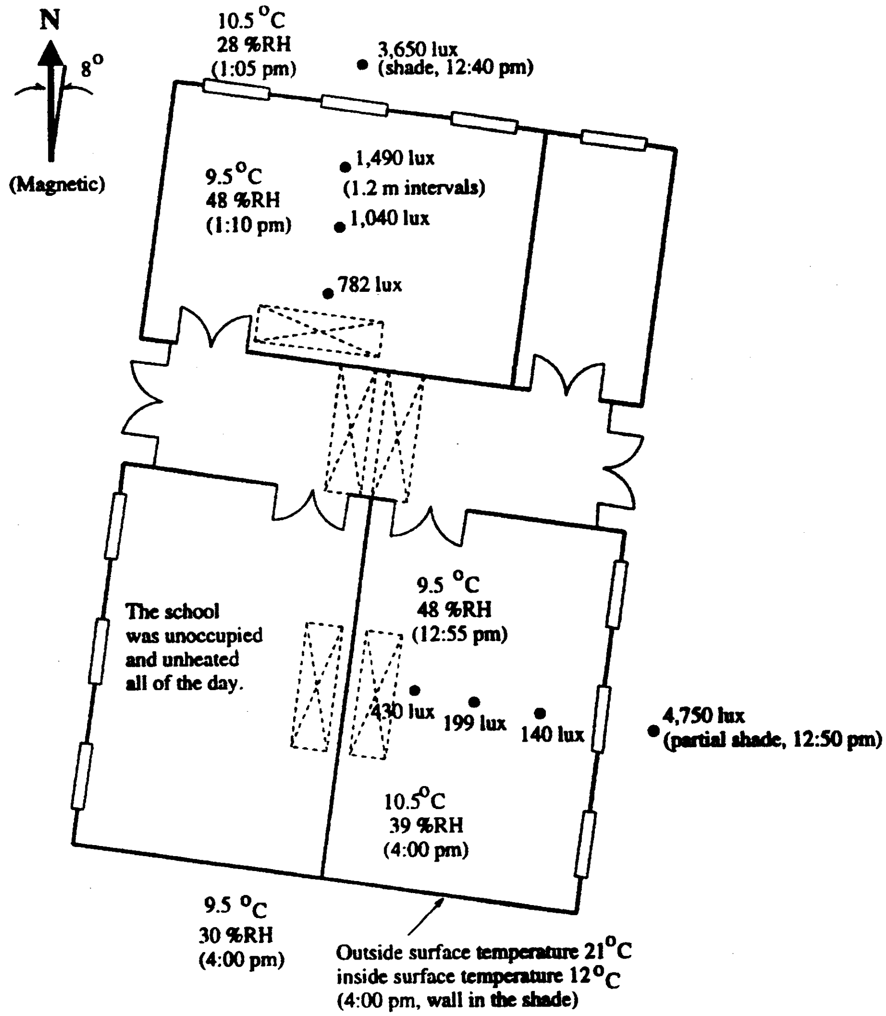


Figure 6-11. Temperature and light levels for Parvak

6.4 Analysis of Air Infiltration Data

It should be noted that a pressure difference of 50 Pascal is quite enormous and corresponds to an airflow rate of 9,819 ft^3/minute for Ghakuch, 9,721 ft^3/minute for Ahmedabad, and 8,421 ft^3/minute for Chitral. If this airflow were to be evenly distributed across the length and height of the buildings, this would correspond to face velocities of 880 miles/hour for Ghakuch (394 m/sec), 872 miles/hour for Ahmedabad (390 m/sec), and 755 miles/hour for Parvak (338 miles/hour).

The schools are very leaky in terms of the ratio of effective leakage area to surface area ratios. This data is summarized in Table 6-5. Weatherizing the south side corridor door on the Ahmedabad and Parvak schools had small effects. A tight house in the United States generally falls in the one $inch^2$ Leakage Area per 100 ft^2 Surface Area range.

School	*Effective Leakage Area / Total Surface Area*	*Leakage Area per 100 ft^2 of Surface Area*
Ghakuch	540 in^2 / 4912 ft^2	11 in^2
Parvak	480 in^2 / 4912 ft^2	10 in^2
Parvak with weatherization	450 in^2 / 4912 ft^2	9 in^2
Ahmedabad	534 in^2 / 4912 ft^2	11 in^2
Ahmedabad with weatherization	514 in^2 / 4912 ft^2	10 in^2

Table 6-5. Summary of effective leakage area (ELA) estimates

Estimations of the natural infiltration rates for the Ahmedabad, Ghakuch, and Parvak Self-Help schools are presented in Table 6-7, Table 6-6, Table 6-8. Despite the fact that the estimated leakage ratios are an order of magnitude larger than tight construction in the US, the natural infiltration rates for the winter months are estimated to be only 1.9, 1.4, and 1.4 ACH for Ahmedabad, Ghakuch and Parvak respectively. This effect is largely dependent on the fact that the buildings are single story and that the documented wind speeds for those regions are very low. For Ghakuch, the mean monthly wind speeds during the school day were estimated to be three times the published data for Gilgit, ranging from 1.1 to 6.8 miles per hour. For Ahmedabad the winds are estimated to be five times as strong as in Gilgit, ranging from 1.9 to 11.3 miles per hour. For Parvak, the winds are in the range of 4.3 to 10.4 miles per hour. These infiltration rates are in the high end for of the range for older houses in the US.

Based on Gilgit Data	Assume T_{indoor} = 72 °F for difference, dT		Wind Speed, 5 *Gilgit's	Air Flow Rate	Infiltration Rate	Post-Weatherization	
Month	$T_{outdoor}$ *in °F*	*dT*	*v in mph*	*Q in ft³/h*	*I in ACH*	*Q in ft³/h*	*I in ACH*
January	37.9	34.1	3.8	27,547	1.9	26,556	1.8
February	43.1	28.9	6.4	30,451	2.1	29,355	2.0
March	53.5	18.5	11.3	39,921	2.8	38,484	2.7
April	62.8	9.2	9.8	33,340	2.3	32,140	2.2
May	69.2	2.8	10.8	34,594	2.4	33,349	2.3
June	77.9	5.9	8.0	27,225	1.9	26,245	1.8
July	83.0	11.0	7.0	25,968	1.8	25,033	1.7
August	81.6	9.6	6.5	24,263	1.7	23,390	1.6
September	73.0	1.0	6.6	21,053	1.5	20,295	1.4
October	61.4	10.6	5.1	21,216	1.5	20,452	1.4
November	48.8	23.2	1.9	21,287	1.5	20,521	1.4
December	39.7	32.3	2.3	25,217	1.7	24,310	1.7
				Yearly mean	1.9		1.85
				Winter mean	**1.9**		**1.85**
				Summer mean	1.9		1.85

Table 6-6. Estimation of natural infiltration rates for Ahmedabad

The infiltration at Ahmedabad is due to poorly fitting doors and windows and the open flues of the stoves (air can leak through the stove flues into the building when not in use). The skylights had a gap between the corrugations of the fiberglass sheets and their mounting frames. Sealing the leaks in one entrance to the building reduced the measured infiltration rate for the whole building by 2.6%. This suggests that closer fitting doors and windows, provided throughout the building, would lead to a significant decrease in the infiltration rate.

Based on Gilgit Weather Data	Assume T_{indoor} = 72 °F for temp. difference, dT		Wind Speed, *3 * Gilgit's*	Air Flow Rate	Infiltration Rate
Month	*$T_{outdoor}$ in °F*	*dT*	*v in mph*	*Q in ft^3/h*	*I in ACH*
January	37.9	34.1	2.3	25,847	1.6
February	43.1	28.9	3.9	25,292	1.5
March	53.5	18.5	6.8	25,898	1.6
April	62.8	9.2	5.9	20,408	1.2
May	69.2	2.8	6.5	18,756	1.1
June	77.9	5.9	4.8	16,577	1.0
July	83.0	11.0	4.2	18,102	1.1
August	81.6	9.6	3.9	16,911	1.0
September	73.0	1.0	3.9	11,398	0.7
October	61.4	10.6	3.1	16,228	1.0
November	48.8	23.2	1.1	20,924	1.3
December	39.7	32.3	1.4	24,712	1.5
				Yearly mean	1.2
				Winter mean	**1.4**
				Summer mean	1.0

Table 6-7. Estimation of natural infiltration rates for Ghakuch

The measured infiltration rates for the Ghakuch building are relatively high for as well. A new design for closer fitting doors and windows should be considered. The holes for the stove flues should also be plugged when the stoves are not in use. No weatherization was performed at the Ghakuch school.

Based on Chitral Data	Assume T_{indoor} = 72 °F for dT		Wind Speed	Air Flow Rate	Infiltration Rate	Post-Weatherization	
Month	*$T_{outdoor}$ °F*	*dT*	*v in mph*	*Q in ft3/h*	*I in ACH*	*Q in ft3/h*	*I in ACH*
January	39.3	32.7	6.1	27,812	1.7	26,080	1.6
February	41.6	30.4	6.8	28,498	1.7	26,724	1.6
March	49.3	22.7	5.5	23,941	1.4	22,450	1.4
April	59.3	12.7	4.9	19,424	1.2	18,215	1.1
May	68.3	3.7	5.9	18,228	1.1	17,093	1.0
June	79.1	7.1	8.8	26,884	1.6	25,210	1.5
July	82.6	10.6	10.4	31,761	1.9	29,784	1.8
August	80.1	8.1	10.4	31,186	1.9	29,244	1.8
September	72.0	0.0	8.1	22,775	1.4	21,357	1.3
October	61.2	10.8	4.3	17,396	1.0	16,313	1.0
November	51.3	20.7	4.6	21,694	1.3	20,343	1.2
December	42.2	29.8	5.8	26,492	1.6	24,843	1.5
				Yearly mean	1.5		1.4
				Winter mean	**1.5**		1.4
				Summer mean	1.5		1.4

Table 6-8. Estimation of natural infiltration rates for Parvak

Weatherizing the east entrance to the Parvak building resulted in a 6.7% reduction in the measured infiltration rate to the whole building.

6.5 Discussion and Recommendations of the Site Survey Results

The extreme seasonal variations in the climate of northern Pakistan pose a particular problem for designing effective year-round thermal performance, since the school buildings are to a large extent passively conditioned and therefore tend to follow the climatic extremes. The solution is not only to improve the thermal insulation of the buildings but also to develop a regime of building operation that responds to the prevailing climate. The success of such an approach relies on regular maintenance of the schools, since if the school is in a poor state of repair it may be impossible to control its thermal performance (due to high infiltration rates, for instance).

Light levels were found to be generally acceptable in all three post-R&D schools. As a result, the simulation work described in the next chapter focuses on thermal issues and does not include assessments of changes in window configurations.

The airflow measurements showed the schools to have leakage areas to surface area ratios much larger, by about a factor of ten, than would be expected in buildings constructed according to current US standards. Air infiltration is due in part to chimney openings for stoves and cracks where window and door frames are inserted in wall openings. However, weather data show that wind speeds are generally low and the calculated airflow rates under expected wind speeds are modest. The calculated airflows appear to be below what would be required by the large number of occupants, according to ASHRAE standards, although air quality problems were not reported by the occupants. As a result, the simulations utilized the calculated airflow rates and did not assess reductions in heating energy due to tighter construction.

As expected, classrooms were generally considered to be too cold in winter. There were also complaints about cold wall surfaces. At Danyore, use of a stove had been discontinued because it was deemed ineffective. The stove was in direct contact with the thermally massive concrete block wall. It is likely that a significant amount of the stove's heat output was directly conducted to the uninsulated block walls. For all these reasons, our simulations are based on placing insulation on the inside surfaces of walls. We recognize that there may be some adverse impact in summer, when bare walls would absorb unwanted heat, but note that open windows and some attention to shading can moderate indoor temperatures.

6.5.1 Building operation

At present the doors and windows of the school buildings are closed when the school is not occupied. This is appropriate during the winter months when heat loss due to ventilation at night should be minimized. However, passive cooling of the building by cool night air could reduce the peak temperatures experienced in the buildings during summer days. The acceptability of leaving windows open at night is subject to security requirements. For some locations, dust migration into the building is also a problem.

In addition to controlling the ventilation in the buildings, shading of the windows on the south and west facades during the summer will help reduce solar gain and peak day time temperatures in the schools. Shading of the windows will also reduce the reported problems of excessive glare. Consideration should also be given to using simple window blinds. Shading of the uninsulated flat roofs should also reduce solar gain during the summer. This could be achieved by supporting a suitable material (cloth or grass) with either a timber or a steel reinforcing bar frame. The shading could then potentially be removed during winter to allow potential solar heating.

As an intermediate measure, prior to the fixing permanent insulation, the winter thermal performance of the buildings could be improved by shielding the internal surfaces of the walls with a temporary insulation material. For instance, heavy cloth or carpet (perhaps disguising straw filled bags behind) could be used. Shielding the mass of the building against heat flow would reduce the time required to heat the classrooms to a comfortable temperature. This approach also has the advantage that the insulation can be removed during summer to enable passive cooling of the building.

6.5.2 Maintenance

In general, maintenance of the structural elements of all the schools visited was good, however the timber elements (windows and doors) were often in need of repair. Window frames were poorly fitted and loose and the windows did not close to give a good seal. Similarly, doors where generally poorly fitted, leaving a large gap at the bottom when closed. All skylights, except those on the pitched roofs, fitted badly or were in need of repair. If the infiltration rate is too large, the thermal performance is difficult to control. It is recommended that a regime of regular maintenance of the school buildings be developed. This should include the plugging of roof holes when stoves and their flues have been removed from the building.

6.5.3 Building Design for Thermal Performance

Recommendations regarding the thermal insulation of the building structure will be made following the computer simulation study, as will comments on the building form. Insulation of the internal surfaces of the walls, floors and ceilings would improve the thermal performance of the building during the winter months. However, an excess of insulation will reduce the ability to passively cool the building during the summer. The results of the simulation study will indicate the degree of insulation required to best compromise between winter and summer thermal performance.

Provisionally, the post-R&D design with pitched roof is the best design of those surveyed. The roof construction has a high thermal resistance and low thermal mass, both of which will increase the thermal performance of the building during the winter. The reflectivity of the corrugated iron roof may also help reduce solar heat gain in the summer. It was also reported that for the two schools of this type studied, although still hot in the summer, the school buildings were cooler than local housing. The fiberglass skylights also limit glare and give an aesthetically appealing quality to the light. The flush fitting skylights may also allow more light to enter the rooms than the raised skylight of the flat roofed buildings. The timber ceiling is likely to have a higher surface temperature than a concrete ceiling, which will increase the perceived thermal comfort. The pitch of the ceiling and its color are also more aesthetically appealing than the cell-like, gray, concrete surfaces of the flat roof buildings.

The thermal resistance of the construction materials (concrete, stone and terracrete), studied are very similar and can be considered to be very poor. The terracrete appears to have the highest thermal mass, the effect of which will be investigated further in the computer simulations.

The reported benefit of cross flow ventilation at Danyore suggests that this might be included in future designs. One possibility, if a central corridor is to be retained, is that windows or vents could be placed in the internal walls to the corridors. Problems of noise transmission between classrooms might limit their use during occupied periods, but their use could enhance ventilation and passive cooling during summer nights. The problems of opening external windows at night during the summer might be resolved by the design of wall vents that are secure against intruders and which limit the amount of dust entering the building.

It is recommended that the design of the windows and doors be reviewed to produce a design that is more robust and closes to provided a good seal against infiltration. A sill placed on the door step would help provide a closer fitting door at the base.

6.5.4 Site Location and Orientation

The effect of building orientation and location of windows will be studied in the computer simulations. The effectiveness of passive solar heating may be limited in some areas since it was reported (Danyore) that during the during the coldest months it is common to have high percentages of cloud cover.

It was apparent that the school at Ghakuch had benefited during the summer from shading by trees and a boundary wall along the south and west facades. Furthermore, trees may provide a suitable form of shading in that they shed their leaves during the autumn and winter and would thus allow more solar gain when required. The poplar trees common to the area would be suitable for this since they are tall enough to provide maximum shading, but shed their leaves early.

6.6 Properties of Construction Materials

6.6.1 General Concrete Mixes

	(cement:sand:aggregate)	
Blinding	1:4:8	
Subfloors	1:3:6	generally 200.0 mm thick.
Floor finish	1:2:4	generally 62.5 mm thick.
T-beams and hollow core roof slabs	1:1.5:3	

Table 6-9. General concrete mixes and thicknesses used in the schools

Steel reinforcing bars are approximately 10.0 mm diameter.
The thermal resistance values presented here do not include the air boundary layers.

6.6.2 Hollow Core Concrete Blockwork

The concrete blockwork is manufactured in the ratio of 1 part cement, 3 parts sand and 8 parts course aggregate.

Density of concrete 2272 kg/m^3 (measured from samples at the Gilgit Housing Board)
Thermal resistance 0.33 m^2K/W (measured at Danyore and Ahmedabad, 203 mm thick)

6.6.3 Semidressed Stone - Granite

Density	2466 kg/m^3	(measured at Ghakuch).
Thermal resistance	0.23 m^2K/W	(measured at Ghakuch, 381 mm thick).

6.6.4 Terracrete

Terracrete is compressed earth stabilized with cement in the ratio of 1 part cement and 10 parts earth.

Density	2253 kg/m^3	(measured at Parvak).
Thermal resistance	0.30 m^2K/W	(measured at Parvak, 300 mm thick).

6.6.5 Flat Roof

The flat roof measured, was constructed from hollow core concrete blocks placed between concrete "T" beams. The external surface of the roof was covered with a 51 mm thick screed and was sealed with a layer of felt and tar.

Thermal resistance 0.44 m^2K/W (measured at Ahmedabad).

6.6.6 Pitched Roof

The pitched roof construction has a ceiling layer of 12.5 mm plywood, a 200.0 mm layer of sirkander grass (reed) insulation, and an outer layer of 24 gauge corrugated galvanized iron sheet.

Thermal resistance 2.32 m^2K/W (measured at Ghakuch).

6.6.7 Windows

All windows in the classrooms had double panes of glass, although the air gap between panes has not been evacuated and sealed.

7. Assumptions Used in the Thermal and Economic Models

This chapter includes the assumptions and details of both the thermal and economic models. The results are analyzed and discussed in the following two chapters. This chapter is organized into three sections:

* thermal modeling assumptions,
* general modeling conventions, and
* economic modeling assumptions.

7.1 Thermal Modeling Assumptions

7.1.1 Temperature Set Point

In the thermal modeling process, the building is modeled as one or more zones. The zone "air" temperature predicted by the SERI-RES simulation program is a weighted average of 7/12 mean radiant temperature and 5/12 dry bulb temperature. This zone temperature is a reasonable predictor of thermal comfort if the ventilation/infiltration rate is low [Haves 1987]. A high ventilation/infiltration would result in draughts and probably require a temperature correction for the wind chill.

A heating temperature set point of 17 °C (62.6 °F) was used for all of the heated runs. Although some occupants had expressed a desirable indoor temperature of 22.2 °C (72 °F), the 17 °C set point was deemed a more realistic target in light of the current situation where the indoor temperatures are frequently well below this point. The average indoor temperature ranges between 8.2 °C to 14.6°C during the school day for the Ahmedabad and Danyore schools during the shoulder months of November and March. The mean daytime indoor temperatures are lower than the mean outdoor daytime temperatures during the shoulder months. This is due to cold nighttime temperature dips that remove heat from the thermally massive building envelope. The rate of heat loss at night is larger than the rate of heat gain during the day. These results are presented in Table 7-1. Therefore, a heating set point of 17 °C translates to a 2.4 °C to 8.8 °C range of improvement over the current situation during the shoulder months. During the winter months of December through February, when the outdoor temperatures are colder, the heating set point of 17 °C will translate to a much a much larger improvement over the current situation. Using a higher or lower temperature set point will directly affect the yearly energy usage significantly.

	November Indoor Avg. School Day Temp. in °C	**November Outdoor** Avg. School Day Temp. in °C	**March Indoor** Avg. School Day Temp. in °C	**March Outdoor** Avg. School Day Temp. in °C
Ahmedabad School	9.8	7.8	10.0	9.8
Danyore School	8.2	11.6	14.6	15.5

Table 7-1. Indoor and outdoor average temperatures during the school day for November 1995 and March 1996.[12]

Although the Ahmedabad and Danyore schools are both constructed with hollow core concrete blocks, the average indoor and outdoor temperatures are different for each site. These differences are the result of several factors:

- stoves were in use in Ahmedabad school while they were not in the Danyore school
- Ahmedabad is a post-R&D school design with classrooms that are 1.82 m narrower than those of the pre-R&D design Danyore School
- Ahmedabad has an average of 35 occupants/classroom and Danyore has 45 occupants/classroom
- the daytime ambient dry bulb temperature is higher at the Danyore School in Gilgit than it is at Ahmedabad in the Hunza Valley

7.1.2 Ground Heat Losses

The ground temperature was modeled as a schedule of temperatures for each month based on the mean ambient dry bulb temperature for the month that precedes the current one by three months. For the ground floor in the Wall.Types section, the ground was modeled using the construction materials, a concrete layer and a stone layer, followed by a direct resistance value of 2.022 m^2 K/W for the earth.

The ground resistance value was calculated using a perimeter loss model that is appropriate for small buildings. In this model, the effective conductance between the ground surface outside the building and the underside of the floor depends on the length of the perimeter, the depth of any insulation and the conductivity of the soil. ASHRAE's rule of thumb for slab-on-grade heat loss is 1.4 W/K per meter of perimeter [ASHRAE 1989, section 25.7, Table 5, equation 6]. Assuming the perimeter is 53.0 m, the UA term is then 74.2 W/K. Diving the UA term (74.2 W/K) by the ground surface area of the entire building (168.8 m^2) results in a U-value of 0.44 W/m^2K. Then the resistance contribution of the inside boundary layer (0.12 m^2K/W) is subtracted (but NOT the outside surface coefficient) giving a metric R value of 2.15 m^2 K/W. Finally, the thermal resistance of the

[12] Data recorded with the assistance of the Aga Khan Housing Office in Gilgit, Pakistan using HOBO® Temp type, remote data loggers manufactured by Onset Computer.

concrete and stone layers in the floor is subtracted from this value to arrive at 2.02 m^2K/W for the R value of the ground.

In summary, the ground was modeled using 8.27 $W/m^2/K$ for the inside side coefficient, R-2.02 as the outer layer in the ground floor in the WALL.TYPES section, 99.9 $W/m^2/K$ for the exterior surface coefficient, and a three-month delayed mean ambient temperature as the scheduled ground temperature in the RUNS section.

7.1.3 Surface Coefficients

The surface coefficient for the bottom side of the ground floor was taken to be 99.9 W/m^2 °C. This high value indicates the direct contact between the floor and the earth below. Interior surface coefficients for the walls, ceilings and floor were modeled as 8.3 W/m^2 °C. The exterior sides of the walls and ceilings had surface coefficients of 18.2 W/m^2 °C and 22.7 W/m^2 °C respectively.

7.1.4 Solar Factors

The SOLAR TO AIR ratio describes the fraction of the Total Solar Available in a zone that goes directly to the zone air temperature node. This fraction depends on the portion of solar energy that is absorbed by non-thermally massive objects such as furniture that is immediately re-radiated as heat. Lacking a measure for this, a value of 15% which near the middle of the typical range was used [Haves 1987].

The SOLAR LOST variable is the fraction of the Total Solar Available inside of the zone that is lost from the system through the windows and skylights. This variable depends on the ratio of the window area to the opaque surface area and the average reflectivity of the interior surfaces. A method for calculating this number is as follows:

1. Estimate the average reflectance of the surface that the incident sunlight first strikes, for example 50%.
2. Of the 50% that survives the first reflection, a fraction hits the windows (window surface area / total room surface area), 5% for example.
3. Approximately 75% of that which strikes the window is lost through transmission to the ambient as light and 25% is reflected or radiated back into the room.
4. Thus, approximately 2% of the initially transmitted light is lost after the first reflection and approximately 48% remains in the room to be reflected a second time.
5. A further 2% of that 48%, i.e. ~1% is lost after the second reflection, and so on, giving a total of approximately 4% (2+1+0.5+0.25...).

The remaining short-wave radiation was distributed onto the walls in proportion to the wall areas and is defined as the wall Solar Coefficient by the SERI-RES program. The sum of the Solar Coefficients, Solar to Air, and Solar Lost is equal to one [Haves 1987].

7.2 General Modeling Conventions

We began with the construction plans and the information from the site surveys. For each school, we prepared a base-case model for the building that included the following sections:

- **Zones**: The school was modeled as five-zone (three classrooms, one office and one corridor) to achieve more detailed results than from modeling the whole building as a single-zone. In the zones section, each individual room was modeled as a separate zone.
- **Internal Gains:** The internal and latent gains, both in kW, were defined in the schedules section. Each person was modeling as generating 70 Watts of sensible heat and 57 Watts of latent heat. Total internal gains were then calculated by multiplying 70*n and latent gains by 57*n, where n is the average number of people in that zone during the operating hours of the schools [ASHRAE, 1989].
- **Materials:** The physical properties of the wall construction materials were measured during the site visit. Properties of other materials such as concrete and wood were taken from widely published values [ASHRAE 1989, chapter 37, Properties of Solids Table].
- **Infiltration rate**: Values were taken from the experimental results from the site surveys.
- **Seasons:** The simulations were made for the winter period October - March. In the seasons section of the SERI-RES input file, the choices for the weekly schedule are All days, Monday through Friday, or Saturday & Sunday. To model the six day (Saturday through Thursday) actual occupancy schedule of the schools, we chose to run the simulations for All days. A method that would have more precisely modeled impact of the one day per week when the building is unoccupied would been to run each simulation for both All days and for Monday through Friday and then averaged the results. The data was then extracted for a representative day that appeared to have reached steady state for that month. The 25th day of each month was used although an earlier day could have been chosen. We then multiplied energy requirement for this day by the number of actual school days in the month. This average day method is consistent with the type of weather data file we used which essentially had data for a prototypical day for each month.
- **Schedule:** Internal occupancy gains, ground temperature, and the HVAC Heat set point were scheduled. The daily occupancy levels were taken from user surveys.
- **Skyline Profile:** This was measured for solar obstruction modeling during the site surveys using a compass, a protractor and a ruler. The readings were taken at a height that was approximately level with the bottom of the window sills.
- **Wall Distinctions:** In the walls section, exterior walls facing different directions, walls between classrooms and corridors, walls between two classrooms, doors, roof, and ground floors were all modeled separately to allow for testing the alternative insulation placement scenarios.
- **Skylights:** Skylights were modeled as windows, using the open sky as the exterior surface. The horizontal and vertical locations of the windows and skylights were all

based on using the bottom right hand corner of each wall (looking from the outside towards the wall).

7.3 Economic Modeling Assumptions

7.3.1 Insulation Material and Labor Costs

Most of the material cost estimates are taken from direct correspondence between the Aga Khan Housing Board for Pakistan and the MIT Program in Building Technology. Mr. Masood Khan, architect and a consultant to the Aga Khan Development Network, suggested that the wall finishing material would be a lime plaster with sand aggregate. Because no thermal data were available for lime plaster, a gypsum based earth-sand plaster was selected with a gypsum to earth-sand aggregate ratio of 1:10. These financial assumptions and cost estimates are summarized in Table 7-2. Please note these estimations neither account for inflation nor discount for a standard interest rate on the investment.

For the expanded polystyrene insulation material, a cost of about 100 Rupees per m^2 corresponds to about 6 ¢ per ft^2 per unit thermal resistance (1.0 ft^2 hr °F/Btu), a cost benchmark that has been used throughout this study. The cost for the straw-MDI is given as 45 Rs/m^2 for R-5 which is approximately 2.5 ¢/R-ft^2. This is 32% higher than the 1.9 ¢/R-ft^2 average material cost for the optimal 10 lb/ft^3, 2% binder load, unscreened boards. The table allows shows a very rough estimate for the labor to manufacture the straw-MDI using a three-person, small-scale, low-tech process. This estimate is 15.8 Rs/m^2 for boards of 2.54 cm thickness which translates to 1.2 ¢/R-ft^2. Using this labor estimate, the total cost of the optimal boards rises to 3.1 ¢/R-ft^2. This is 24% higher than the figure used in the payback analysis and 48% lower than the cost of expanded polystyrene. It must be noted however, that past experience with the Self-Help Schools suggests the community members may be willing to perform the labor without monetary payment.

In the Northern Areas of Pakistan the costs for wood lath and studs are extremely high, about an order of magnitude more, per wall surface area, than that of the insulation itself and about two orders of magnitude higher than the plaster finish. Wood lath traditionally has been used to support a plaster surface over insulation material installed in studded wall cavities in the United States. For masonry walls, as are used in the Self-Help schools, there are no load-bearing stud walls. According to Table 7-2, the studs that are needed to support the lath are over twice the cost of the lath itself. Alternatives to using a high-cost wood stud and lath lattice for plaster include:

* use a fabric cover or tapestry instead of plaster to provide a more acceptable wall appearance
* use chicken wire in place of wood lath
* add an acceptable surface color pigment and a fine grain outer layer when fabricating an insulation board from straw
* paint the surface of the insulation board directly
* directly plaster the insulation board

In the US, expanded polystyrene insulation must be covered with a material that is thick enough to keep the insulation temperature lower than the ignition temperature for 30 to 60 minutes. This regulation ensures that the occupants of a burning building are able to flee before the foam insulation releases toxic fumes. This rules out paint or fabric covers for polystyrene. Direct plastering on extruded polystyrene appears feasible based on commercial products now available. MIT has examined an extruded polystyrene sample covered by a plastic mesh similar to chicken wire and a cement-based plaster coating. The coating must be thick enough to meet the fire safety requirements. The straw-MDI insulation boards however, contain very low percentages of petrochemical binder (between one to four percent by mass fraction). For this reason, the fire safety requirements for the straw insulation board are anticipated to be very low, similar to those for plywood. Additionally, the straw boards accept plaster extremely well without the addition of a surface mesh.

It is expected that the method of attaching the insulation board to walls and ceilings will involve some type of screw and washer fastening system. Pilot holes can be drilled into stone or concrete block using an ordinary electric hand drill and a masonry drill bit. Then, either masonry screws or ordinary screws with plastic anchors are used to support the insulation board and fastening system. Several feasible attachment systems have been explored at MIT. Examples of these systems are: screws with metal fasteners or braces; wire clips braced between the layers of concrete block; and a network of jute string in tension around masonry screws. The costs of the attachment systems have not been included in this analysis.

Installation Costs		Work Rate	Pay Rate	
		m^2/hr	*Rs/hour*	*Rs/m^2*
Labor to hang insulation with lathe		18.6	18	1
Labor to plaster		5.6	18	3
Rough estimate of labor to manufacture straw-MDI boards with a low-tech, distributed, small-scale process; at a board thickness of 2.54 cm		1.1	18	15.8
Wood Lath and Stud Costs[13]				
wood lath *includes installation*				1399
wood studs *includes installation*				3294
Plaster Costs[14]	**Bulk Cost**	**Density**	**Thickness**	
Gypsum to earth-sand aggregate ratio of 1:10	*Rs/kg*	*kg/m^3*	m	
Gypsum Cost *material only*	4.4	1682	0.0012	9
Earth (high clay content) and sand cost *material only*	1	1682	0.0115	19
Total plaster material cost				28
Insulation Costs				
Expanded Polystyrene for R-5				97
Expanded Polystyrene for R-10				194
Straw-MDI insulation, R-5				45
Straw-MDI insulation, R-10				90
Fuel Costs	*Rs/kg*			
Scrap Wood	2.25			

Table 7-2. Summary of cost data used to perform the economic analysis

[13] The wood lath and wood stud costs were supplied via a fax from Ms. Nabeela F. Nazir, our primary contact with the Aga Khan Housing Board for Pakistan (AKHBP) in Karachi, Pakistan. This information did not include a breakdown showing raw material costs and labor to prepare a finished wood product.

[14] The gypsum cost was gathered on the site survey expedition and the sand cost was supplied via fax from the AKHBP.

8. Computer Energy Simulations

8.1 Overview of Computer Simulation Based Research

This chapter summarizes the results of computer energy simulations of four Self-Help Schools in the Northern Areas and Chitral, Pakistan. This study was conducted with the SERI-RES/PC Version 1.2 computer energy simulation program. SERI-RES is a building thermal simulation model intended for applications where the performance of the building envelope is the primary concern. This program has the capability to calculate dynamic heat flows. The following description gives a general sense of how the program works:

> *A thermal model of the building is created by the user. It is translated into mathematical form by the program. The mathematical equations are then solved repeatedly at time intervals of one hour or less for the period of simulation, usually one year. The mathematical representation of the building is a thermal network with non-linear, temperature dependent controls. The mathematical solution technique uses a combination of forward finite differences, Jacobian iteration, and constrained optimization [Haves 1987].*

In order to use any dynamic simulation program, it is necessary to have both an input file or model of the building and a weather file that describes the environmental conditions in which the building exists. The following sections contain descriptions of the modeling techniques and assumptions as well as the details concerning preparation of the weather files.

8.2 Relative Comparison vs. Exact Prediction

Although we have given considerable thought to every detail in the input files, this in no way guarantees that we will be able to accurately predict the exact amount of energy usage in the buildings. A number of factors limit our accuracy:

- The temperature set point we selected, 17 °C, will differ in practice. Schools that are currently unheated use no heating fuel hence there would fuel savings if insulation is installed. However, as will be discussed later, there would be an improvement in thermal comfort. Room temperatures in heated schools will fluctuate due to door openings, occupancy differences, and variable rates of wood addition.
- Energy use is directly impacted by the flow of air into and out of a building. We have measured this airflow rate as part of the site surveys. However, the airflow rate varies with indoor-outdoor temperature difference, wind speed, wind direction, and with occupant use of windows and doors.
- We have estimated that a typical wood-burning stove has an efficiency of 50%. A higher efficiency stove will reduce the estimated fuel use and therefore reduce the savings due to thermal insulation. On the other hand, a lower efficiency unit will increase the baseline fuel usage and therefore increase the savings.

- Weather data used in our simulations represent a single, average day for each month. In practice, outdoor temperature and solar radiation will vary from these averages.
- A related note on the weather data is that the Ahmedabad, Danyore, and Ghakuch schools are all simulated using the same weather file based on the Gilgit region. Local geographic variations in the weather conditions will also limit the accuracy of predicting exact energy consumption.

To determine an accurate measure of yearly heating energy use at a given school, it would be more exact to weigh all of the fuel before it is burned. Nevertheless, our simulation tool is an extremely useful prescriptive tool. We can effectively model the heat losses and gains through the ground, walls, windows, infiltration/exfiltration, roof, people, and equipment. Then we can make strategic changes to discern very real differences in the building's thermal performance. These relative comparisons are the most important benefit of the computer simulation method.

To compare the economic benefits of the alternative solutions, we use the relative energy reduction as a guide to estimate the relative payback periods for the alternative scenarios. From this process, we can then make decisions based on the best available quantitative estimates and the associated non-quantitative factors such as the impact on local community development and the environment.

8.3 Modeling and Simulation Process

The first step involved generating a baseline input file for each school in its current construction. The importance of developing baseline models of the schools is that they provide a reference point from which it is possible to test the effects of changing strategic variables. Once baseline input models for all of the schools were prepared, they were then systematically modified to evaluate the impact of alternative thermal insulation scenarios on the amount of energy required for winter heating.

As was discussed in the previous chapter, after consideration of the tradeoffs between winter and summer thermal performance, we concluded that the optimal placement of the insulation is on the internal surfaces of the buildings. Therefore, all of the scenarios presented here involve applying insulation to the inside surfaces of walls and ceilings.

8.3.1 Winter Insulation Scenarios

Table 8-1 shows the insulation placement scenarios that were simulated and then compared with the baseline case for the Ghakuch school. The 'Scenario' column in Table 3 refers to the nomenclature used to track the different scenarios.

Scenario	Significance to Insulation Placement
1	Inside surface of the external walls for the occupied rooms.
2	Inside surface of the external walls for the occupied rooms except for the walls which face the Southeast direction.
3	Inside surface of the external walls and the ceilings of the occupied rooms.
4	Inside surface of all walls for occupied rooms except for those shared with another occupied room.
5	Inside surface of external walls for occupied rooms, the occupied side of the walls shared between occupied rooms and the corridor, and half the given insulation on each side of the walls shared between two occupied rooms; i.e. for the case where external walls are insulated a material with a resistance of 0.88 m^2 K/W (5.0 hr ft^2 °F/Btu) , 0.44 m^2 K/W (2.5 hr ft^2 °F/Btu) is placed on each side of the walls shared between occupied rooms.
6	Inside surface of external walls for occupied rooms, the occupied side of walls shared between an occupied room and the corridor, half the given R-value amount on each side of the walls shared between two occupied rooms, and on the ceilings of the occupied rooms.

Table 8-1. Thermal insulation scenarios compared with the baseline Ghakuch model

All of the insulation placement scenarios listed here were tested using two levels of insulation: 0.88 m^2 K/W (5.0 hr-ft^2-°F/Btu, or R-5) and 1.76 m^2 K/W (10.0 hr-ft^2-°F/Btu, or R-10). A thermal resistance of 0.88 m^2 K/W (5.0 hr-ft^2-°F/Btu) is equivalent to the thermal resistance value for 25 mm (1 inch) of extruded polystyrene. The results of the Ghakuch simulations, described in the next chapter, show Scenarios 1, 2, and 4 to be very promising and were also run as test simulations for the Parvak, Ahmedabad, and Danyore schools. Scenarios 3 and 6 both involve insulating the ceilings of the occupied rooms. These scenarios do not have favorable payback periods for Ghakuch and Parvak due to the fact that their existing roofs are already better insulated than the walls. The cost of adding additional insulation to the ceiling outweighed the relative benefit of reducing heat losses.

Additional winter simulations were also performed on the Ahmedabad and Danyore schools. Table 8-2 and Table 8-3 summarize these simulations.

Scenario	**Significance to Insulation Placement**
5b	Inside surface of external walls for occupied rooms and the full amount of insulation on both sides of the walls shared between two occupied rooms
7	Inside surface of the external walls of the occupied rooms, the occupied side of all walls shared with the corridor, and the ceilings of the occupied rooms

Table 8-2. List of additional thermal insulation scenarios simulated for the Ahmedabad school

Scenario	Significance to Insulation Placement
3b	Inside surface of external walls for occupied rooms and all of the ceilings
7b	Inside surface of the external walls of the occupied rooms, the occupied side of the all shared corridor walls, and all of the ceilings
7	Inside surface of the external walls of the occupied rooms, the occupied side of all walls shared with the corridor, and the ceilings of the occupied rooms

Table 8-3. List of additional thermal insulation scenarios simulated for the Danyore school

A detailed listing of the SERI-RES input files can be found in Chapter 12, SERI-RES Input Files, page 179.

8.3.2 Summer Insulation Scenarios

For the purpose of evaluating the impact of thermal insulation on thermal comfort during the hot summer months, nineteen variations were run on the Ahmedabad school during the month of August. The three basic scenarios that were tested were the uninsulated baseline case and insulation placement scenarios 3 and 7. Variations of the basic scenarios included modifying the occupancy schedule, the window ventilation schedule, and substituting the basic wall material to cover the three school construction types. Passive window ventilation strategies were simulated by scheduling the building's air infiltration rates. The alternate summer simulation scenarios are summarized in Table 8-4.

Alternate Scenarios Simulated for Ahmedabad in the Month of August
1. Uninsulated base case with all windows always closed
2. Uninsulated, windows open all of the time
3. Uninsulated base case with all windows open from 8 am to 3 PM
4. Uninsulated, windows fully open from 9 PM to 10 AM and fully closed 10 AM to 9 PM, using a summer occupancy schedule of 7 AM to 2 PM
5. Scenario 3, insulation placed on the inside surface of the external walls and the ceilings of the occupied rooms, with the windows always closed
6. Scenario 3, windows open all of the time
7. Scenario 3, windows fully open from 9 PM to 10 AM and fully closed 10 AM to 9 PM, using a summer occupancy schedule of 7 AM to 2 PM and shades on southerly facing windows in occupied rooms
8. Scenario 3, windows fully open from 9 PM to 10 AM and fully closed 10 AM to 9 PM, using a summer occupancy schedule of 7 AM to 2 PM, shades on ALL southerly facing windows (including the corridor)
9. Scenario 3, substitute terracrete block for hollow core concrete blocks in the walls, windows fully open from 9 PM to 10 AM and fully closed 10 AM to 9 PM, using a summer occupancy schedule of 7 AM to 2 PM, shades on ALL southerly facing windows (including the corridor)
10. Scenario 3, substitute granite for hollow core concrete blocks in the walls, windows fully open from 9 PM to 10 AM and fully closed 10 AM to 9 PM, using a summer occupancy schedule of 7 AM to 2 PM, shades on ALL southerly facing windows (including the corridor)
11. Scenario 7, insulation placed on the occupied side of walls shared with the corridor, the external walls and the ceilings of the occupied rooms, with the windows open all night
12. Scenario 7, windows open 8 am to 3 PM
13. Scenario 7, windows shut all of the time
14. Scenario 7, windows half opened from 9 PM to 10 AM and fully closed 10 AM to 9 PM, using a summer occupancy schedule of 7 AM to 2 PM and shades on southerly facing windows in occupied rooms
15. Scenario 7, windows fully open from 9 PM to 10 AM and fully closed 10 AM to 9 PM, using a summer occupancy schedule of 7 AM to 2 PM and shades on southerly facing windows in occupied rooms
16. Scenario 7, windows fully open from 9 PM to 10 AM and fully closed 10 AM to 9 PM, using a summer occupancy schedule of 7 AM to 2 PM, shades on ALL southerly facing windows (including the corridor)
17. Scenario 7, substitute granite for hollow core concrete blocks in the walls, windows fully open from 9 PM to 10 AM and fully closed 10 AM to 9 PM, using a summer occupancy schedule of 7 AM to 2 PM, shades on ALL southerly facing windows

18. Scenario 7, substitute terracrete block for hollow core concrete blocks in the walls, windows fully open from 9 PM to 10 AM and fully closed 10 AM to 9 PM, using a summer occupancy schedule of 7 AM to 2 PM, shades on ALL southerly facing windows (including the corridor)
19. Scenario 7, only 21 people/classroom instead of 35 people/classroom, windows fully open from 9 PM to 10 AM and fully closed 10 AM to 9 PM, using a summer occupancy schedule of 7 AM to 2 PM and shades on southerly facing windows in occupied rooms

Table 8-4. List of thermal insulation scenarios simulated for the Ahmedabad school in the month of August.

9. Results of Computer Energy Simulations

This chapter contains the results of the energy simulations along with a brief analyses of the data. An overall summary and discussion of the important results occurs in the next chapter. For the Ghakuch, Ahmedabad, and Parvak schools, the results are presented in terms of:

- the annual heating energy requirement for one school building;
- the cumulative resource savings in terms of kilograms of wood saved over five, ten, and fifteen year periods for two school buildings;
- an overview of the insulation, installation, and plaster finishing costs for two school buildings;
- a cumulative monetary payback comparison of four insulation strategies for two buildings at each school for both straw and expanded polystyrene insulation over five, ten, and fifteen year periods; and
- the impact of classroom occupancy levels on the yearly heating requirements for one building at each school.

For the Danyore school, the annual heating energy requirement is presented for alternative insulation placement scenarios. The results of the simulated and actual recorded indoor and outdoor temperature profiles for the Ahmedabad and Danyore schools are then described and discussed. Finally, the results of the summer simulations for Ahmedabad involving strategies for passive ventilation, occupancy scheduling, and shading are presented

***Figure 9-1.** Ghakuch annual heating energy requirement under alternative scenarios.*

This set of results applies to the estimated energy requirement for heating one building at the Ghakuch Self-Help school and does not include the energy conversion efficiency of the heating device. For example, if a stove with a 50% efficiency is used, the actual fuel requirements would be twice as much as the heating energy requirements presented here. This graph shows a 33% reduction in yearly energy consumption can be achieved by applying the 0.88 m^2K/W (R-5) level of insulation to all of the walls except for the southeast wall. The idea behind this scenario is that for the operation of a school, the southeast surface might not need to be insulated due to incident solar radiation during the morning hours. This radiative heat gain would ideally offset the conductive heat losses leaving through the southeastern wall. This benefit would of course be mitigated after a few hours. The next along the progression towards more insulation coverage is Scenario 1, insulating all the external walls, which posts a 49% reduction. Scenario 4, insulating all the walls of the occupied rooms except those shared with another occupied room yields a 54% reduction over the base case, and Scenario 5, insulating all walls of occupied rooms, shows a 55% reduction. This result indicates there is negligible benefit derived from insulating both sides of the walls shared between occupied rooms. Scenario 6, insulating all walls and ceilings of the occupied rooms, also posts a 55% reduction. This confirms there is relatively no benefit to adding insulation to ceilings at Ghakuch because there is sufficient insulation in the original construction. The simulations using the 1.76 m^2K/W

(10.0 hr ft^2 °F/Btu, or R-10) level of insulation follow a similar energy reduction path: 38%, 57%, 62%, 62%, and 63%. The overall trend of the energy consumption as insulation is added can be described as a decreasing exponential function. In order to select the optimal insulation strategy for a given school it is necessary to compare these projected energy savings with the financial and wood resource requirements. The best insulation values per unit of insulation are given by placement Scenarios 1 and 4.

Figure 9-2. *Ghakuch resource savings in terms of kilograms of wood saved over several time periods.*

These numbers are based on calculations that assume woodstoves of 50% energy conversion efficiency are used to heat two buildings at the Ghakuch school. These savings do not discount any amount for the cellulosic material (wood, straw, etc.) that might be used to manufacture the insulation. This graph highlights the natural resource problem associated with high desert regions such as the Northern Areas and Chitral, Pakistan. In the least effective insulation case, 0.88 m^2 K/W (5.0 hr ft^2 °F/Btu, or R-5) under Scenario 1, where only the external walls of the occupied rooms are insulated, there is a projected savings of 25,538 kilograms of wood over a 10 year period. If this type of savings was equaled in 250 of the school buildings in the region, there would be an overall savings of 3.2 million kilograms of wood over a ten year period. In practice the wood savings are likely to be smaller because the schools are not presently being heated to 17 °C. Nevertheless, the argument stands that there is a large quantity of wood that would not have to be collected for combustion heating. This would surely have a positive impact on both the environment and the quality of life for the people living in these areas.

Figure 9-3. *Overview of insulation, installation, and plaster finishing costs for two buildings of the Ghakuch school.*

This graph shows the breakdown between insulation material cost and the cost of installation and surface finish with plaster. The installation costs include labor and plaster materials but do not include material costs for a wall attachment system. The results are given for two quantities of insulation at the two most promising insulation placement scenarios. We also analyzed the possibility of using a wood stud and lathe system for wall attachment and plastering but the cost proved to be prohibitive. This chart should be used in conjunction with the financial resource allocation requirement to determine which projects are able to be financed.

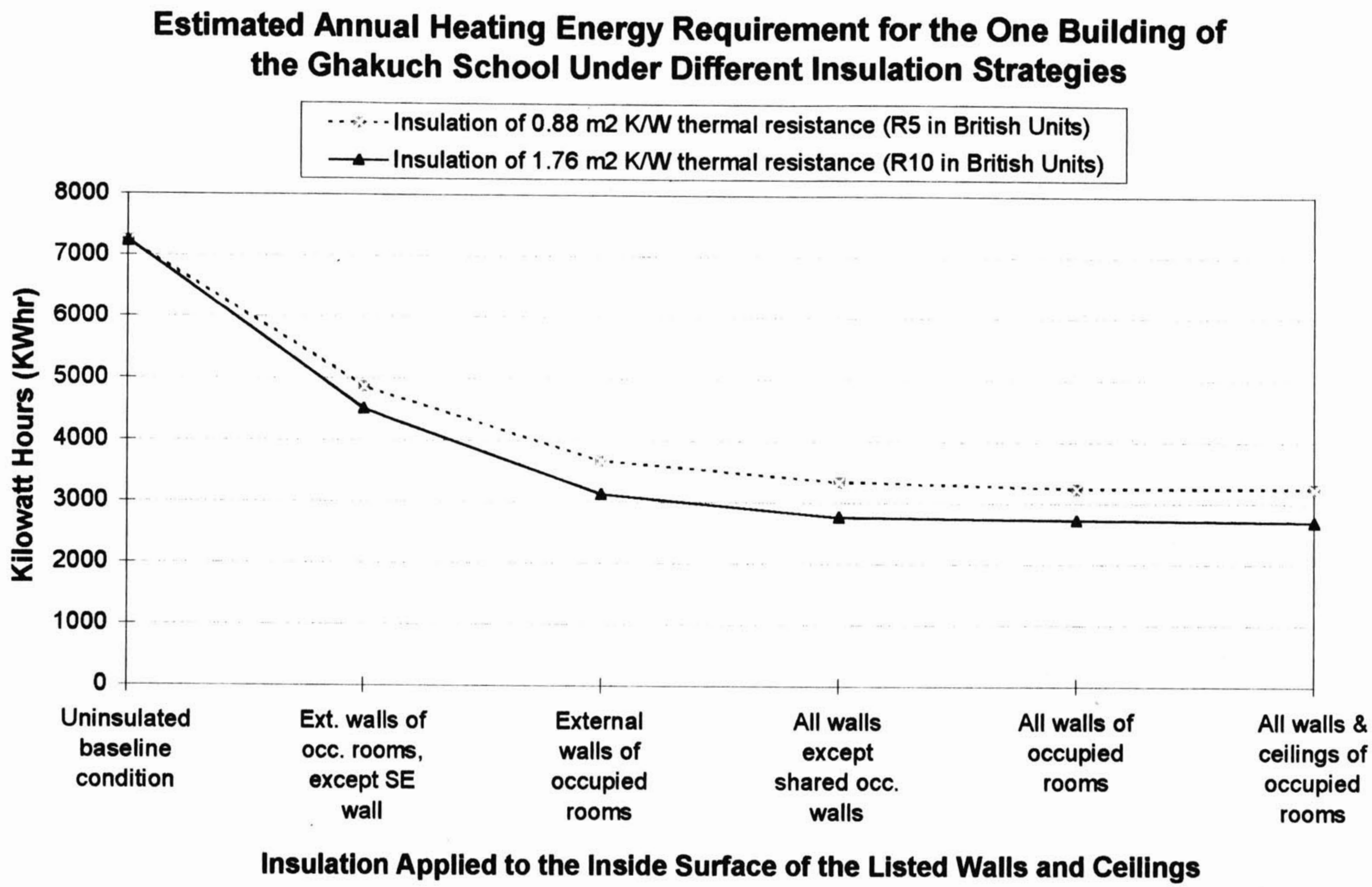


Figure 9-1. Ghakuch annual heating energy requirement under alternative scenarios.

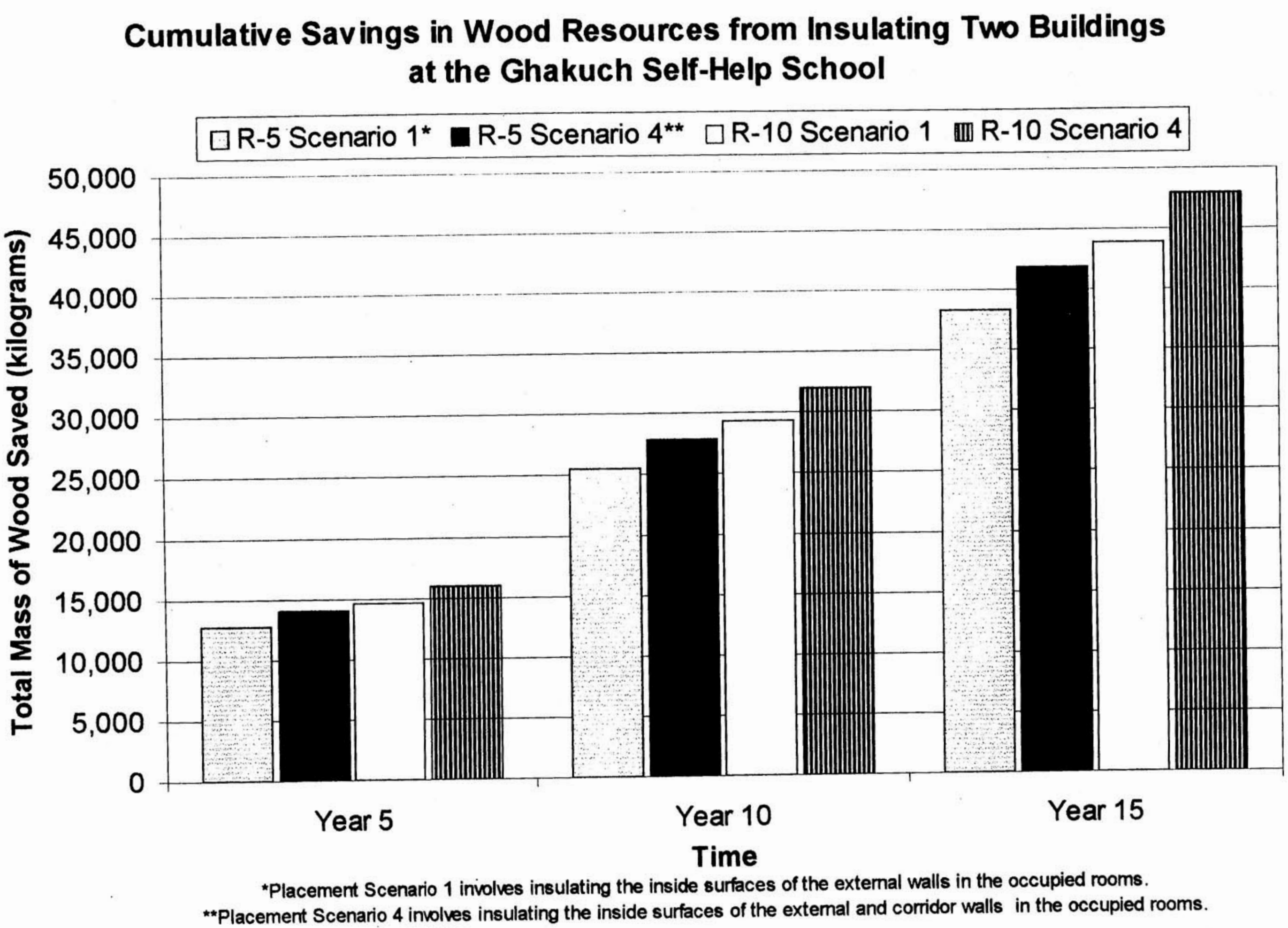


Figure 9-2. Ghakuch resource savings in terms of kilograms of wood saved over several time periods

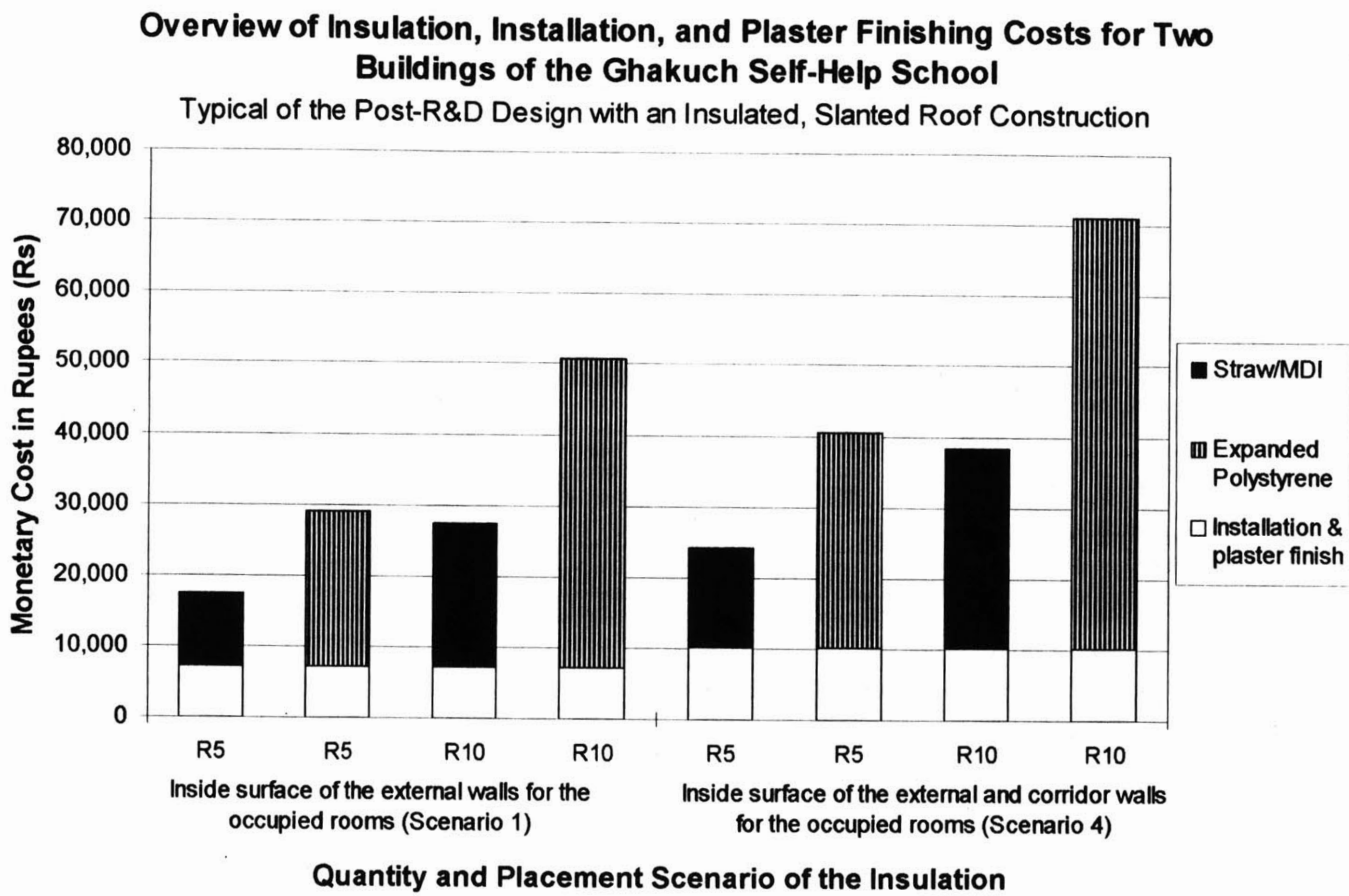


Figure 9-3. Overview of insulation, installation, and plaster finishing costs for two buildings of the Ghakuch school.

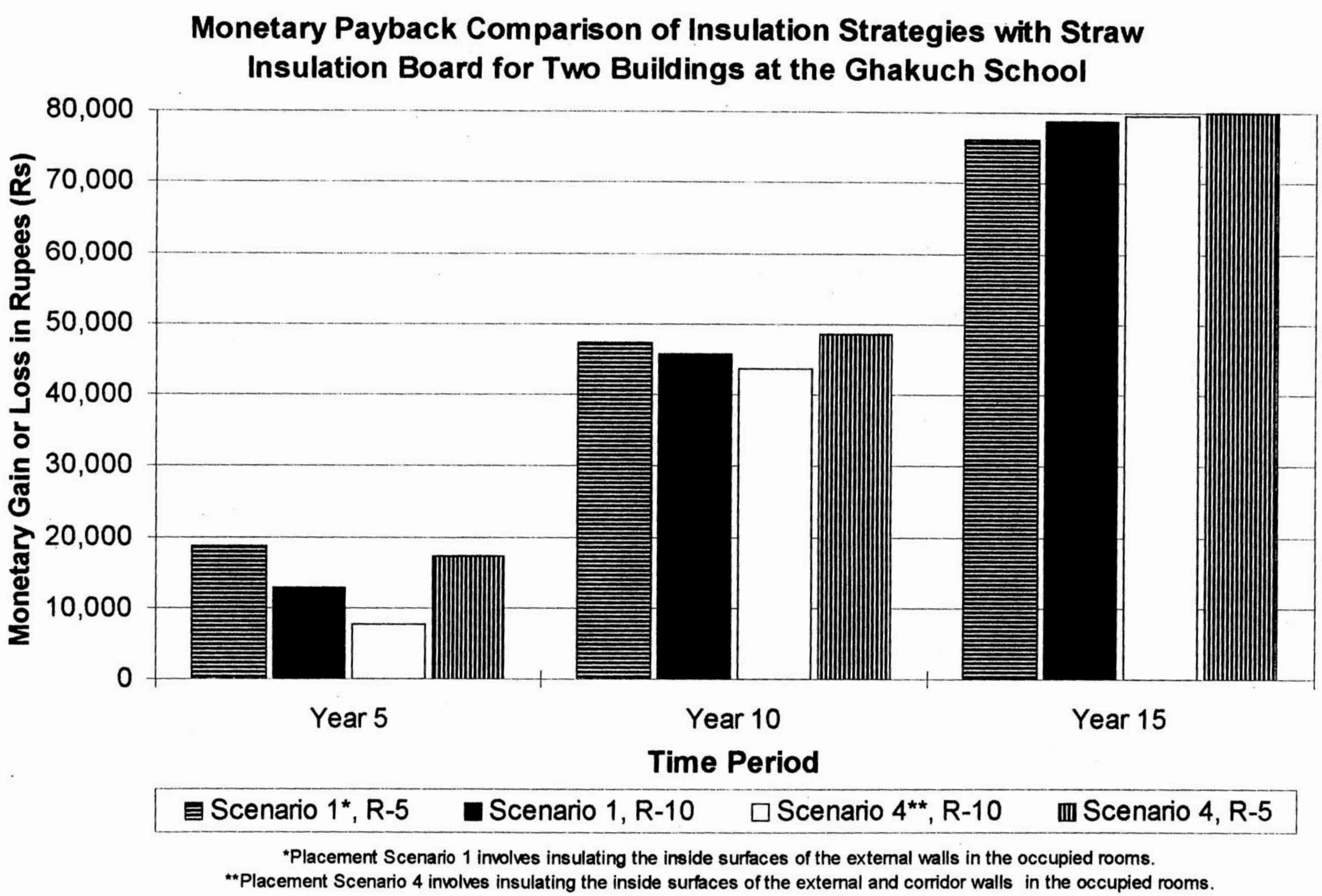


Figure 9-4. Cumulative monetary payback comparison of four insulation strategies with straw insulation board at the Ghakuch school Please note these estimations neither account for inflation nor discount for a standard interest rate on the investment.

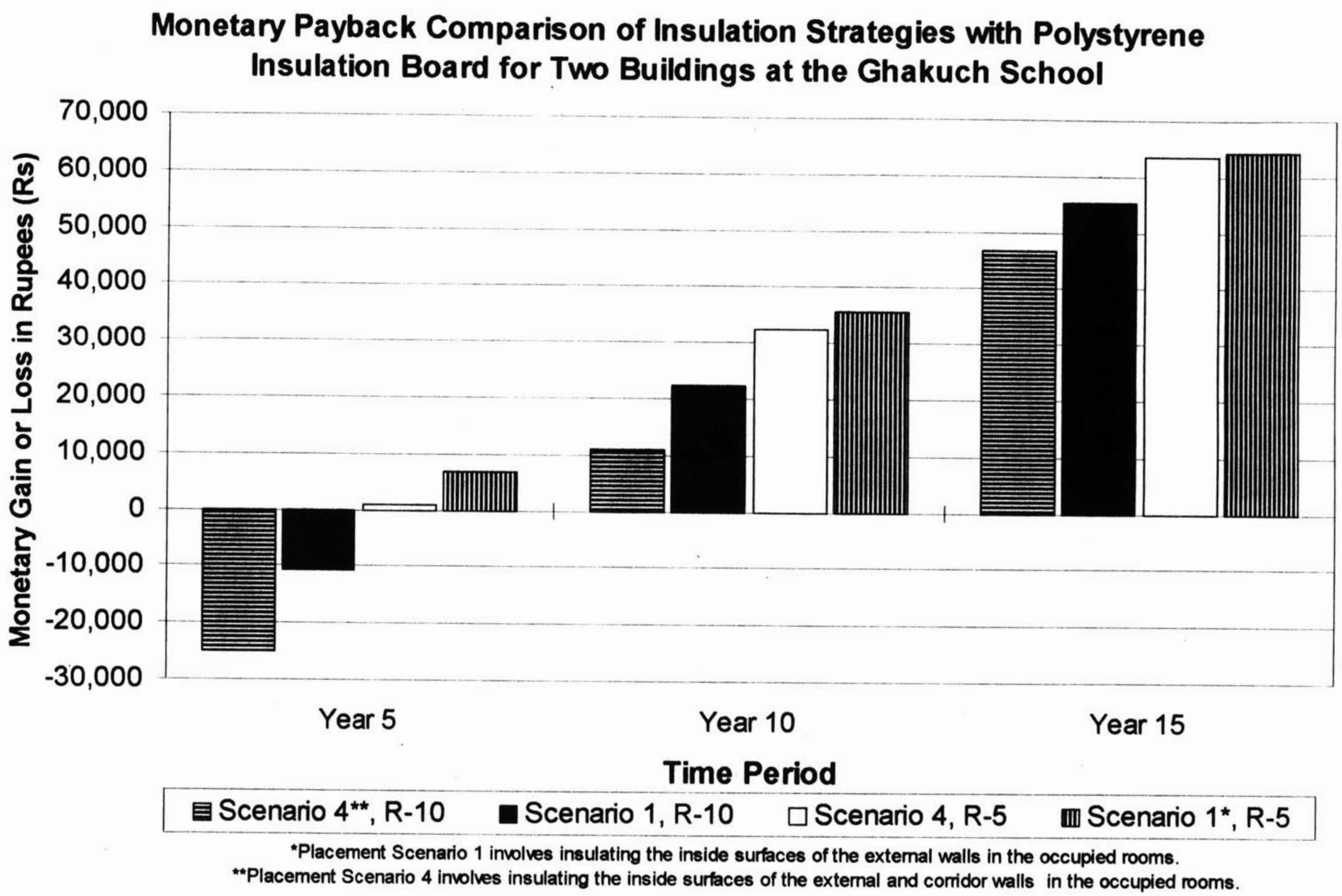


Figure 9-5. Cumulative monetary payback comparison of four insulation strategies with expanded polystyrene insulation the Ghakuch school

Please note these estimations neither account for inflation nor discount for a standard interest rate on the investment.

Figure 9-4. *Cumulative monetary payback comparison of four insulation strategies with straw insulation board for two buildings at the Ghakuch school over five, ten, and fifteen year periods.*

The best payback after five years is yielded by the Scenario 1, insulating the inside surfaces of the external walls in the occupied rooms, at the R-5 insulation level. This is the scenario with the lowest total volume of insulation material. However, after 15 years the cumulative payback yield drops to the bottom of the group. It is important to note that all of the graphed alternatives have break even periods of less than five years. When analyzed in conjunction with *Figure 9-2*, Scenario 4, insulating all the walls of the occupied rooms except those shared with another occupied room, at the R-10 quantity level is the clear winner. Please note these estimations neither account for inflation nor discount for a standard interest rate on the investment.

Figure 9-5. *Cumulative monetary payback comparison of four insulation strategies with expanded polystyrene insulation board for two buildings at the Ghakuch school over five, ten, and fifteen year periods.*

The best payback after five years is again yielded by the Scenario 1, insulating the inside surfaces of the external walls in the occupied rooms, at the R-5 insulation level. Because of the higher material cost, Scenarios 1 and 4 at the R-5 level are the only ones to have break even periods of less than five years. After 15 years, the cumulative payback yield of Scenario 1 is still the best. However when analyzed in conjunction with *Figure 9-2*, the most attractive alternative appears to be Scenario 4 at the R-5 level. Once again, these estimations neither account for inflation nor discount for a standard interest rate on the investment.

Figure 9-6. *Ahmedabad annual heating energy requirement under alternative scenarios.*

This set of results applies to the estimated energy requirement for heating one building at the Ahmedabad Self-Help school and does not include the energy conversion efficiency of the heating device. The results shows a 25% energy reduction between the uninsulated base case and Scenario 2 with 0.88 m^2 K/W (R-5) of insulation applied to all of the external occupied walls except the southeast wall. There is a 37% reduction in the first scenario (insulating all the external walls) and a 41% reduction in the fourth insulation scenario (insulating all the walls of occupied rooms except those shared with another occupied room), in both cases for 0.88 m^2 K/W (5.0 hr ft^2 °F/Btu, or R-5) of insulation. These percentages are smaller than those seen in Figure 1a for Ghakuch. The reason for this is once again the result of the existing roof construction. Because the roof and walls are basically of the same construction in Ahmedabad, it is necessary to insulate both the roof and walls in order achieve the optimal benefits. This effect is observed in the sixth, seventh, eighth, and ninth data points on the graph. These scenarios give a tight range of 67%-68% reduction.

When the insulation is doubled to 1.76 m^2 K/W (10.0 hr ft^2 °F/Btu, or R-10), energy reductions are 30% for Scenario 2, followed by 44% for Scenario 1 and 47% reduction for Scenario 4. When insulation is added to the roof, the range of reductions jumps to 76%-79%.

Figure 9-7. *Ahmedabad resource savings in terms of kilograms of wood saved over several time periods.*

These numbers are based on calculations that assume woodstoves of 50% energy conversion efficiency are used to heat two buildings at the Ahmedabad school. These savings do not discount any amount for the cellulosic material (wood, straw, etc.) that might be used to manufacture the insulation. In the least effective insulation case, 0.88 m^2 K/W (5.0 hr ft^2 °F/Btu, or R-5) under Scenario 3, where only the external walls and the ceilings of the occupied rooms are insulated, there are projected savings of 39,386 kilograms of wood over a 10 year period. If this type of savings were equaled in 250 of the school buildings in the region, there would be an overall savings of 4.9 million kilograms of wood over a ten year period.

Figure 9-8. *Overview of insulation, installation, and plaster finishing costs for two buildings of the Ahmedabad school.*

This graph shows the breakdown between insulation material cost and the cost of installation and surface finish with plaster. The installation costs include labor and plaster materials but do not include material costs for a wall attachment system. The results are given for two quantities of insulation at the two most promising insulation placement scenarios. This chart should be used in conjunction with the financial resource allocation requirement to determine which projects are able to be financed.

Figure 9-9. *Cumulative monetary payback comparison of four insulation strategies with straw insulation board for two buildings at the Ahmedabad school over five, ten, and fifteen year periods.*

All of the graphed alternatives have break even periods of less than five years. The best payback after five years is yielded by the Scenario 3, insulating the inside surfaces of the external walls and ceilings of the occupied rooms, at the R-5 insulation level. Indeed this scenario continues to have the best payback after fifteen years, although not by very much. All of the scenarios are within 14,000 Rs of each other after ten years. After 15 years, both R10 scenarios are within 2,000 Rs of the leader. When analyzed in conjunction with *Figure 9-7*, Scenarios 3 and 7, both at the R-10 level, seem to be the better choices. Please note these estimations neither account for inflation nor discount for a standard interest rate on the investment.

Figure 9-10. *Cumulative monetary payback comparison of four insulation strategies with expanded polystyrene insulation board for two buildings at the Ahmedabad school over five, ten, and fifteen year periods.*

After five years, none of the alternatives have reached the break even point although the two R-5 scenarios are close. Over a fifteen year period, these two alternatives clearly have better financial paybacks than the others. They also have comparable wood savings to each other. In this case, resource allocation budgets would probably dictate the final selection of placement scenario. It should be noted that if a payback period longer than fifteen years were analyzed, the scenarios with greater quantities of insulation would eventually garner greater cumulative savings than the scenarios with lower insulation quantities. Once again, these estimations neither account for inflation nor discount for a standard interest rate on the investment.

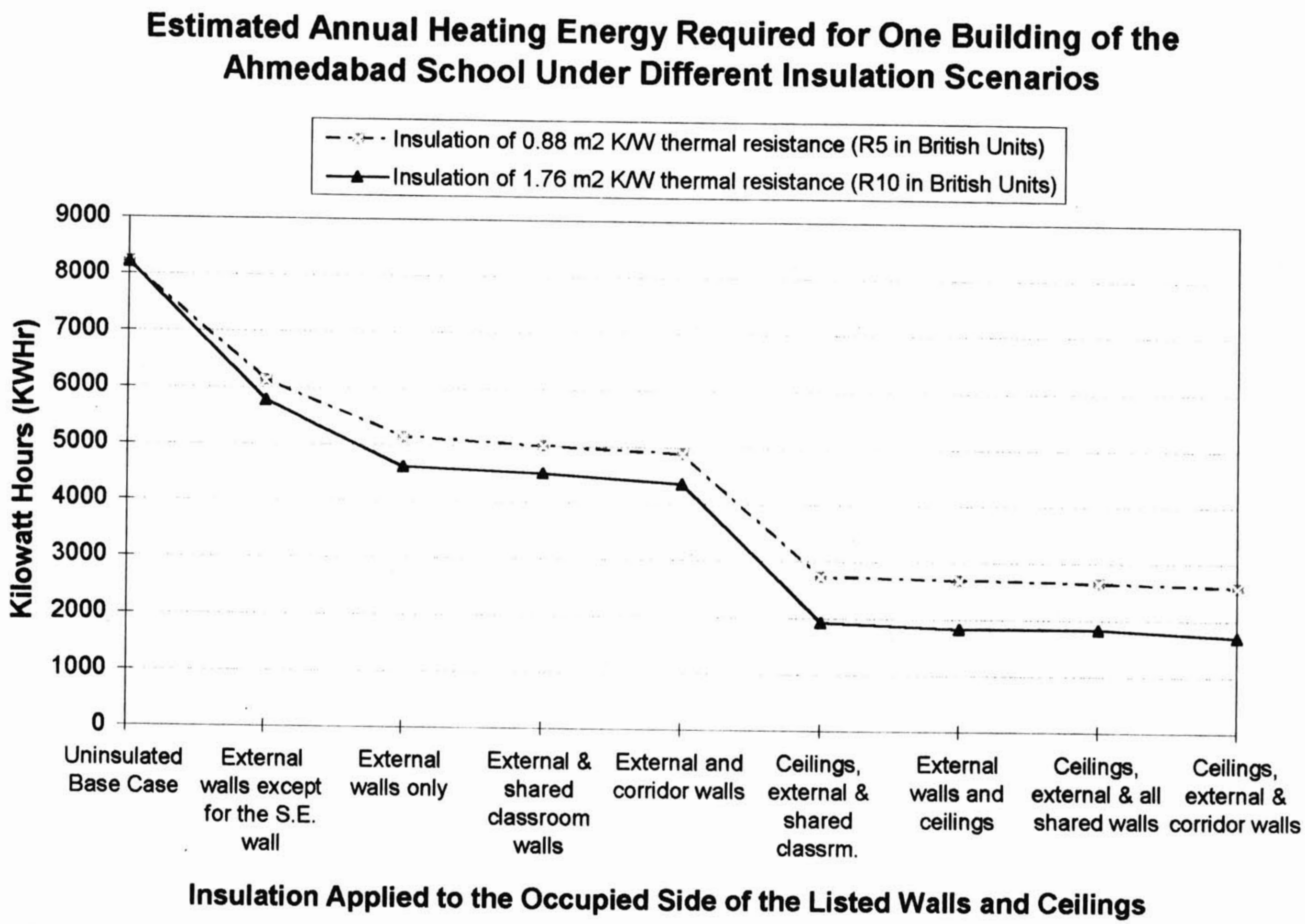
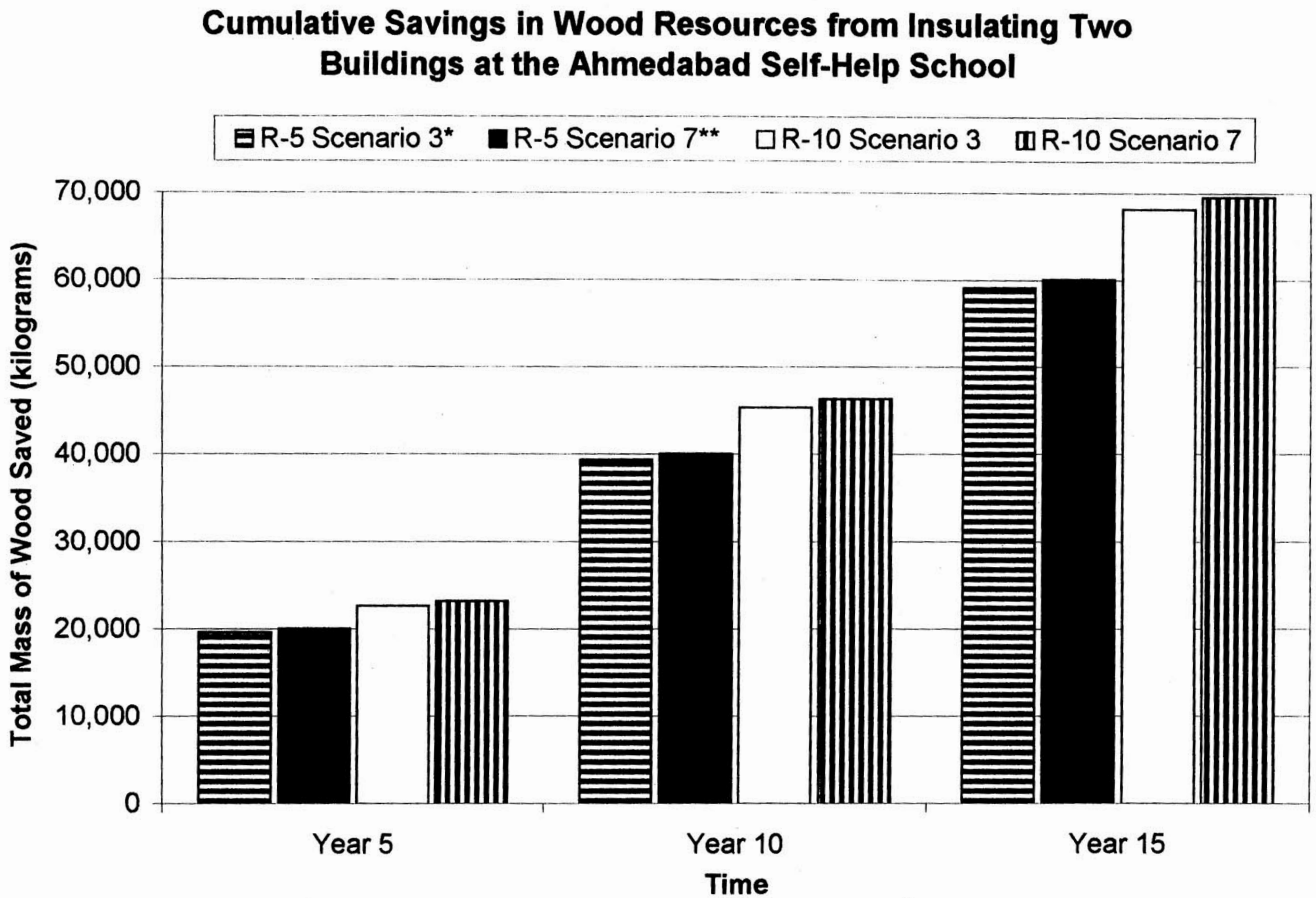


Figure 9-6. Annual heating energy requirement for one building of the Ahmedabad school under alternative insulation placement scenarios



*Placement Scenario 3 involves insulating the inside surfaces of the external walls and ceilings in the occupied rooms.
**Placement Scenario 7 involves insulating the inside surfaces of the external walls, corridor walls and ceilings in the occupied rooms.

Figure 9-7. Ahmedabad resource savings in kilograms of wood saved over several time periods

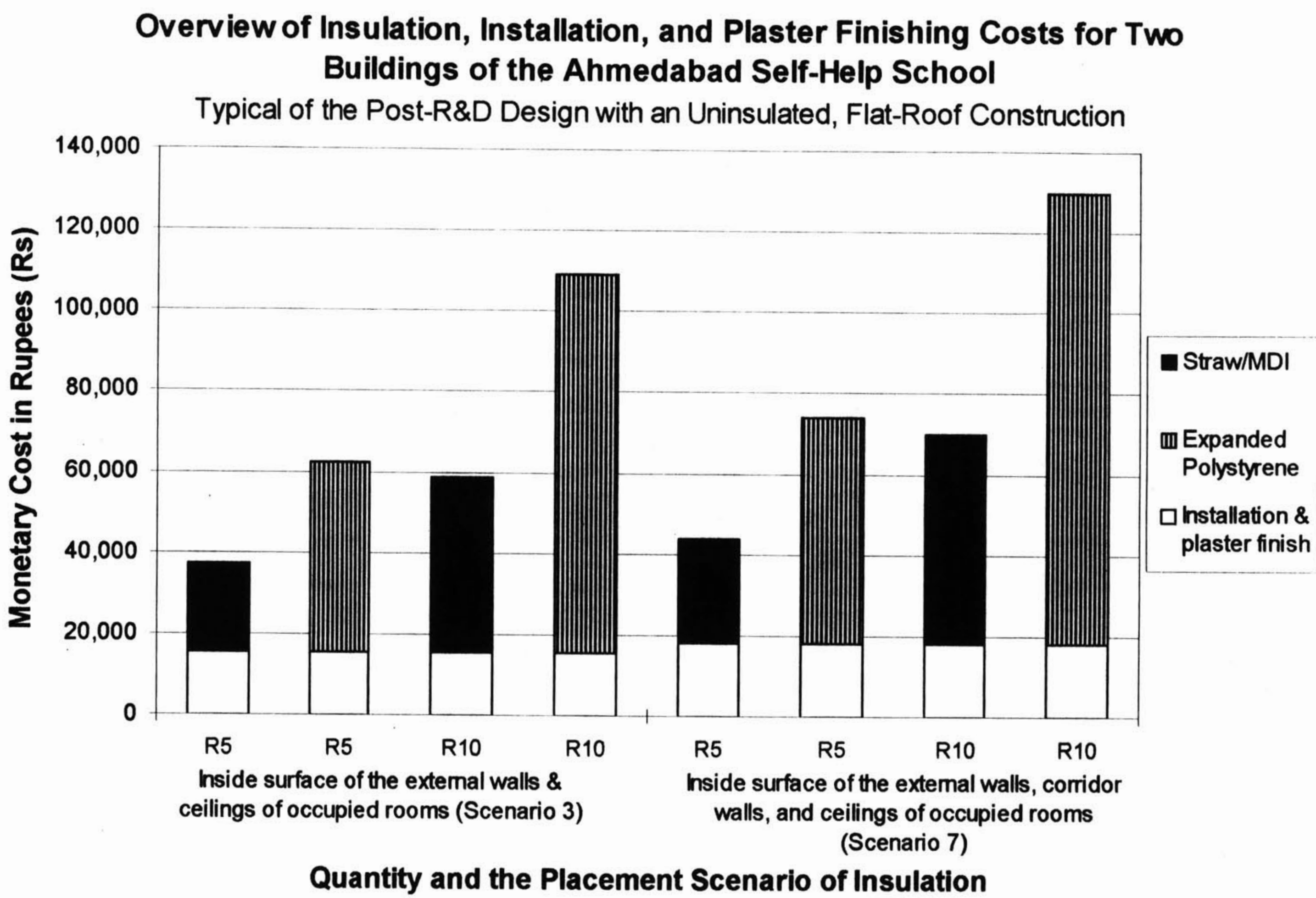


Figure 9-8. Overview of insulation, installation, and plaster finishing costs for two buildings of the Ahmedabad school.

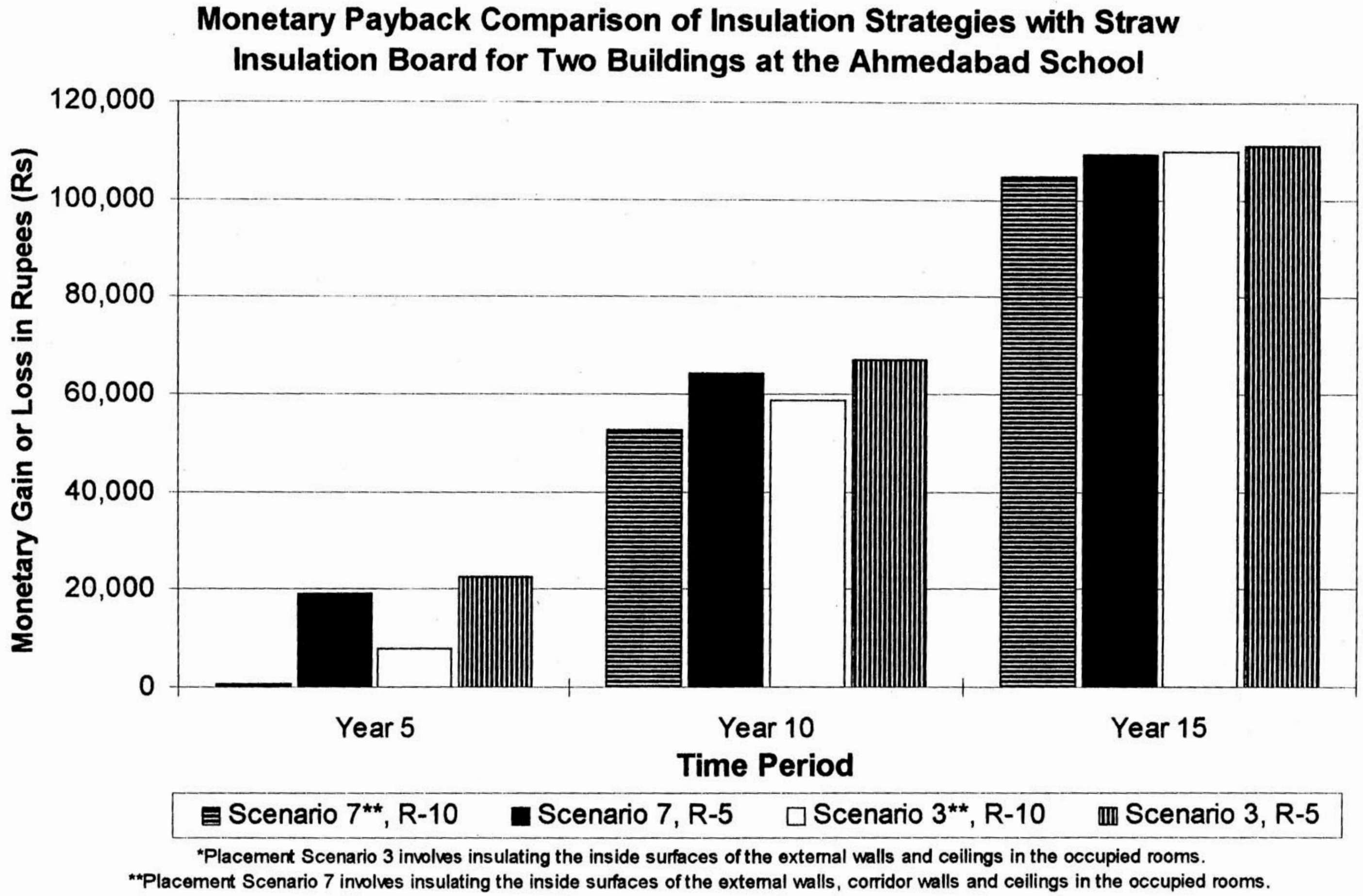


Figure 9-9. Cumulative monetary payback comparison of four insulation strategies with straw insulation board at the Ahmedabad school

Please note these estimations neither account for inflation nor discount for a standard interest rate on the investment.

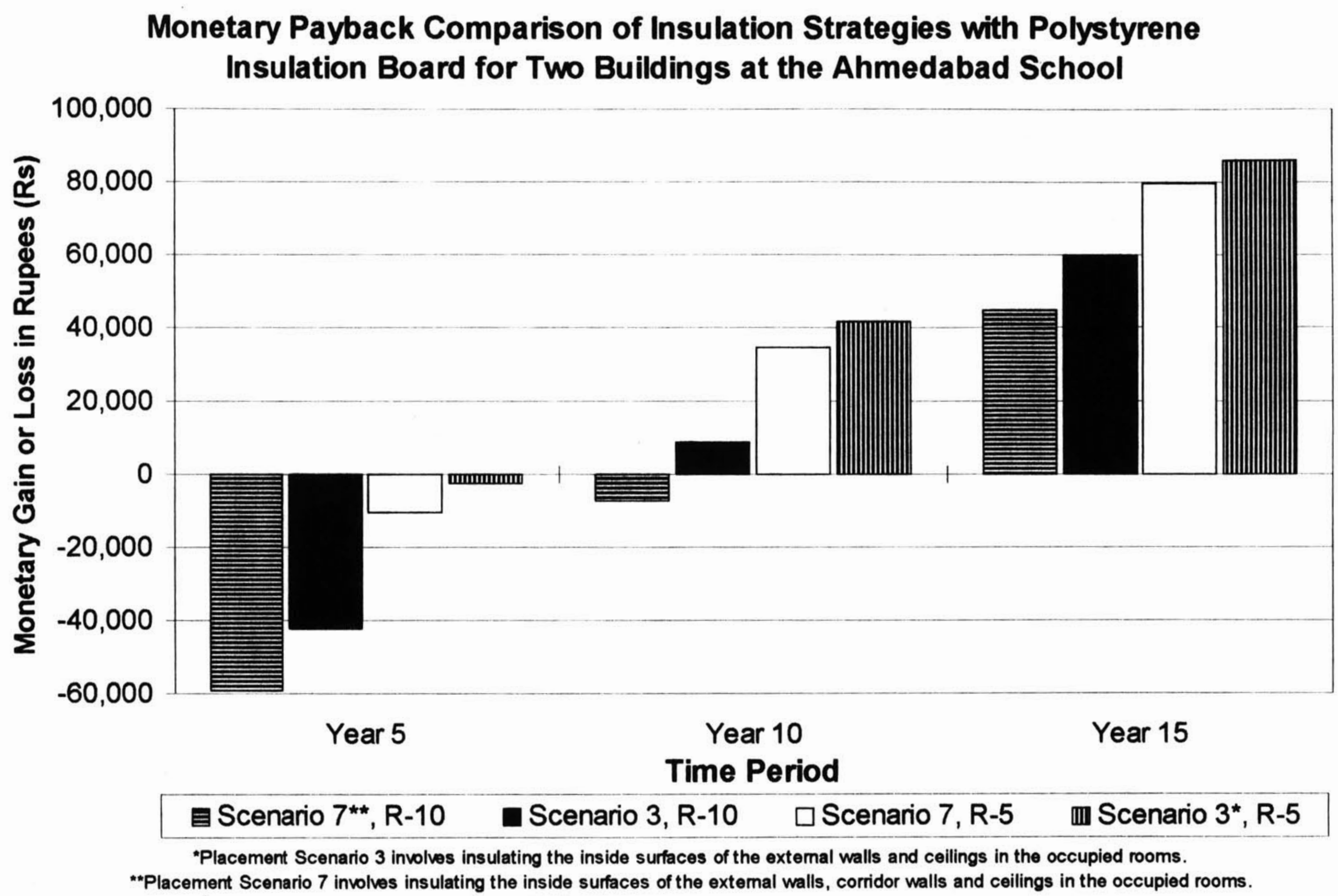


Figure 9-10. Cumulative monetary payback comparison of four insulation strategies with expanded polystyrene for two buildings at Ahmedabad

Please note these estimations neither account for inflation nor discount for a standard interest rate on the investment.

Figure 9-11. *Parvak annual heating energy requirement under alternative scenarios.*

This set of results applies to the estimated energy requirement for heating one building at the Parvak Self-Help school. These savings do not discount any amount for the cellulosic material (wood, straw, etc.) that might be used to manufacture the insulation. Parvak has the lowest baseline heating energy requirement of all the schools. This is mainly the result of a relatively large average class size, 35 people/classroom, and a well insulated roof. The weather for the Chitral region is also several degrees Celsius warmer in the winter than the Gilgit region. The results indicate a 39% energy reduction between the uninsulated base case and the Scenario 2 with 0.88 $m^2 K/W$ (5.0 hr $ft^2 °F/Btu$, or R-5) of insulation applied to all of the external occupied walls except the southeast wall. There is a 55% reduction in the Scenario 1, insulating all the external walls, and a 56% reduction in the Scenario 4, insulating all the walls of occupied rooms except those shared with another occupied room, in both cases for 0.88 $m^2 K/W$ (5.0 hr $ft^2 °F/Btu$, or R-5) of insulation. The energy reductions under Scenario 1 are larger than those seen in Ghakuch while the improvements observed with Scenario 4 are nearly identical to Ghakuch.

When the insulation is doubled to 1.76 $m^2 K/W$ (10.0 hr $ft^2 °F/Btu$, or R-10), energy reductions are 45% for Scenario 2, followed by 62% for Scenario 1 and 64% reduction for Scenario 4.

Figure 9-12. *Parvak resource savings in terms of kilograms of wood saved over several time periods.*

These numbers are based on calculations that assume woodstoves of 50% energy conversion efficiency are used to heat two buildings at the Parvak school. These savings do not discount any amount for the cellulosic material (wood, straw, etc.) that might be used to manufacture the insulation. In the least effective insulation case, 0.88 $m^2 K/W$ (5.0 hr $ft^2 °F/Btu$, or R-5) under Scenario 1, where only the external walls of the occupied rooms are insulated, there is a projected saving of 13,903 kilograms of wood over a 10 year period. If this type of improvement was equaled in 250 of the school buildings in the region, there would be overall savings of 1.7 million kilograms of wood over a ten year period.

Figure 9-13. *Overview of insulation, installation, and plaster finishing costs for two buildings of the Parvak school.*

This graph shows the breakdown between insulation material cost and the cost of installation and surface finish with plaster. The installation costs include labor and plaster materials but do not include the material costs for a wall attachment system. The results are given for two quantities of insulation at the two most promising insulation placement scenarios. This chart should be used in conjunction with the financial resource allocation requirement to determine which projects are able to be financed.

Figure 9-14. *Cumulative monetary payback comparison of four insulation strategies with straw insulation board for two buildings at the Parvak school over five, ten, and fifteen year periods.*

Only the R-5 scenarios have break even periods of less than five years. The best payback after five years is yielded by the Scenario 1, insulating the inside surfaces of the external walls of the occupied rooms, at the R-5 insulation level. Indeed this scenario continues to have the best payback after fifteen years. After 15 years, the R-10 level of Scenario 1 has saved only 4,189 Rs less than the R-5 level of Scenario 1. Taking into account the additional wood savings, Scenario 1 at the R-10 level appears to be the better choice. Please note these estimations neither account for inflation nor discount for a standard interest rate on the investment.

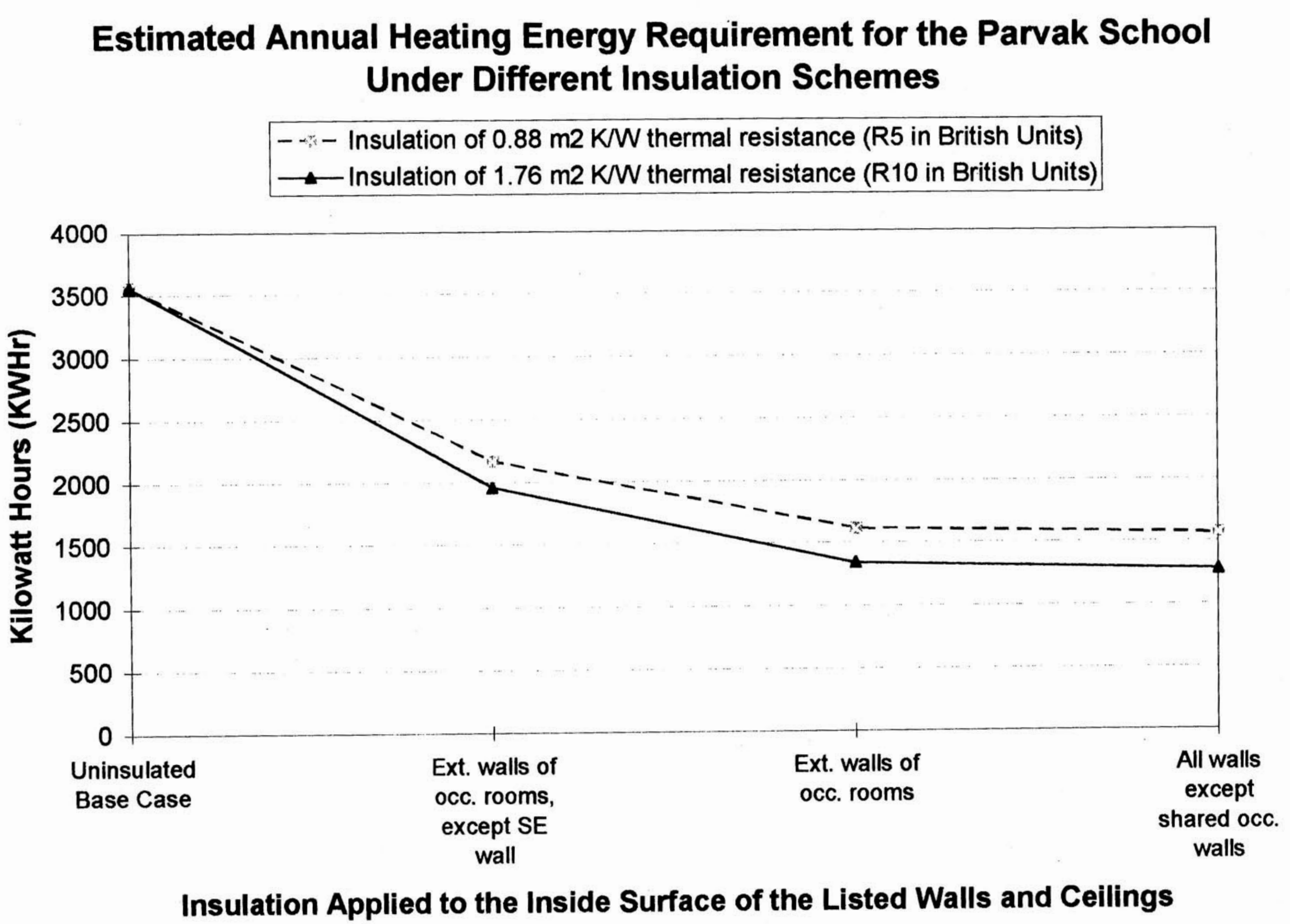


Figure 9-11. Parvak annual heating energy requirement under alternative scenarios.

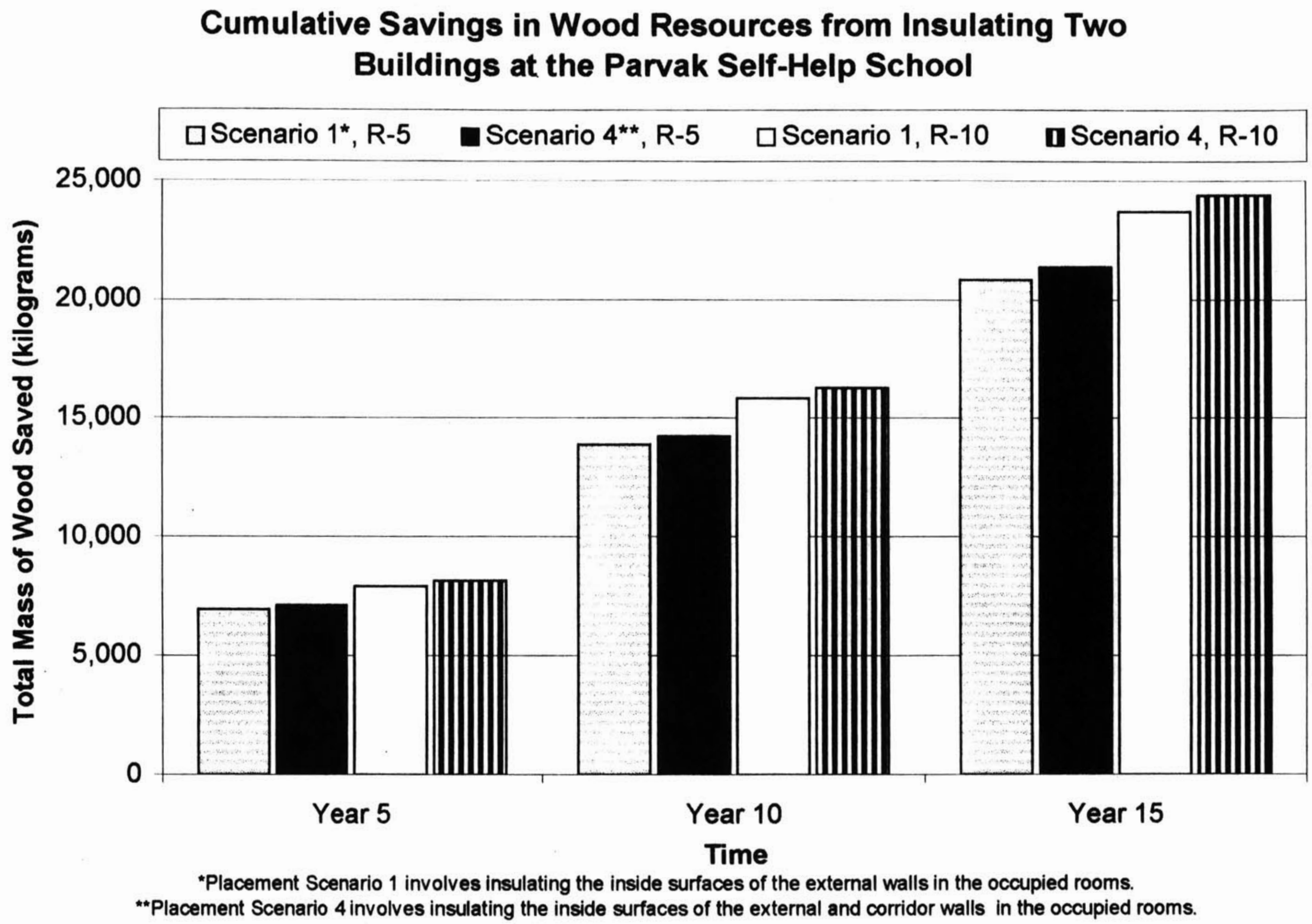


Figure 9-12. Parvak resource savings in terms of kilograms of wood saved over several time periods

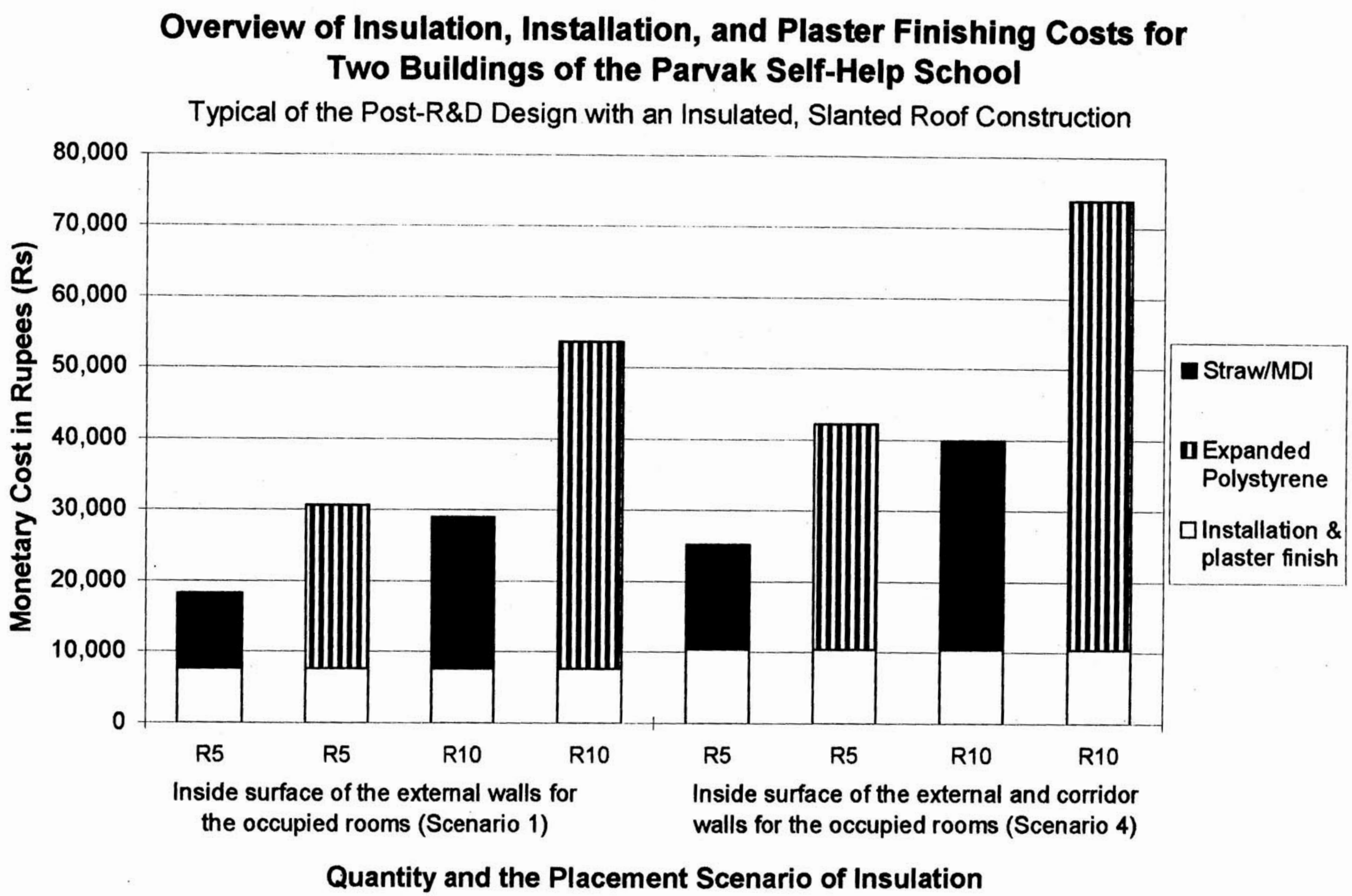


Figure 9-13. Overview of insulation, installation, and plaster finishing costs for two buildings of the Parvak school

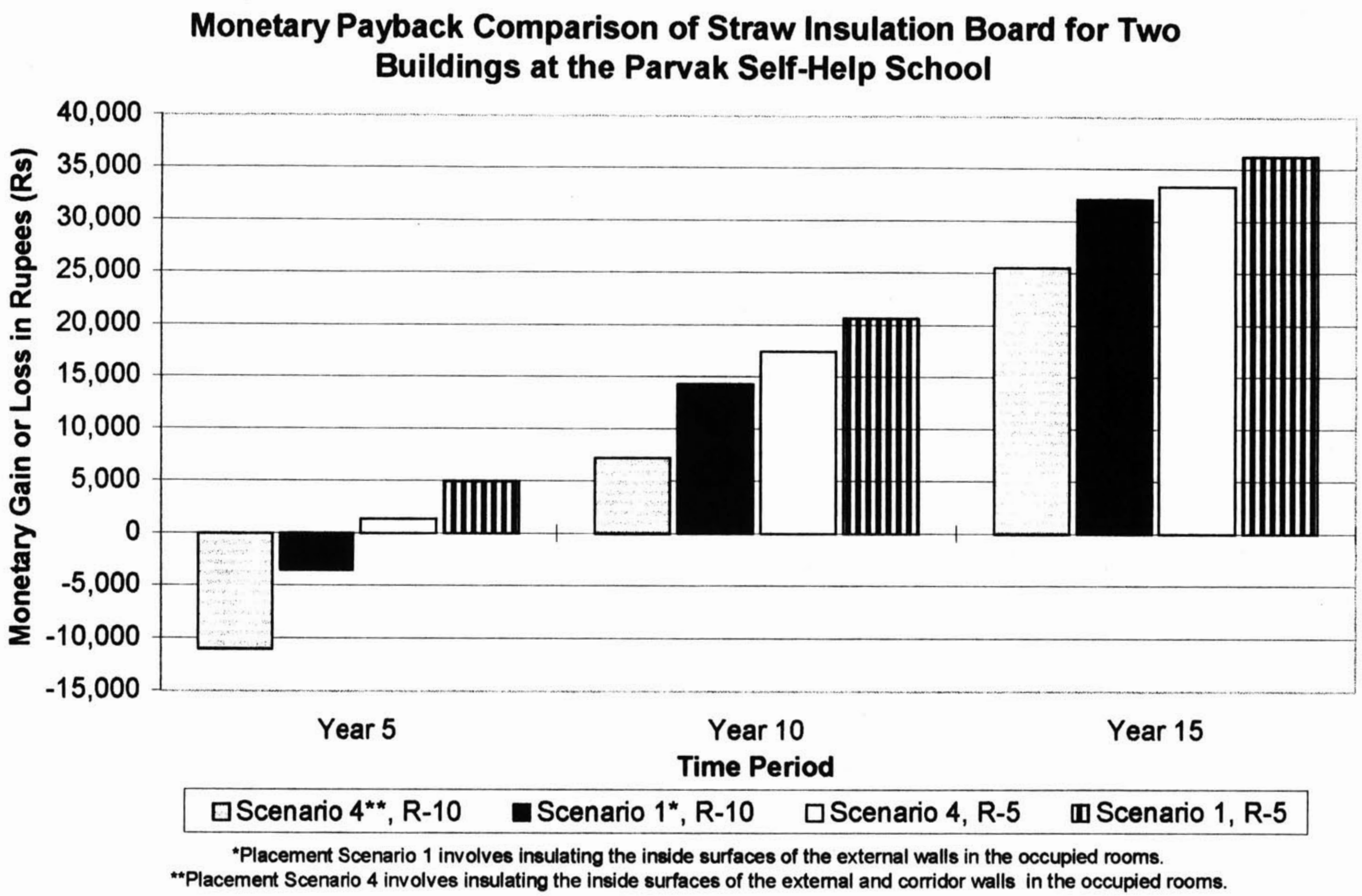


Figure 9-14. Cumulative monetary payback comparison of four insulation strategies with straw insulation board for two buildings at the Parvak school

Please note these estimations neither account for inflation nor discount for a standard interest rate on the investment.

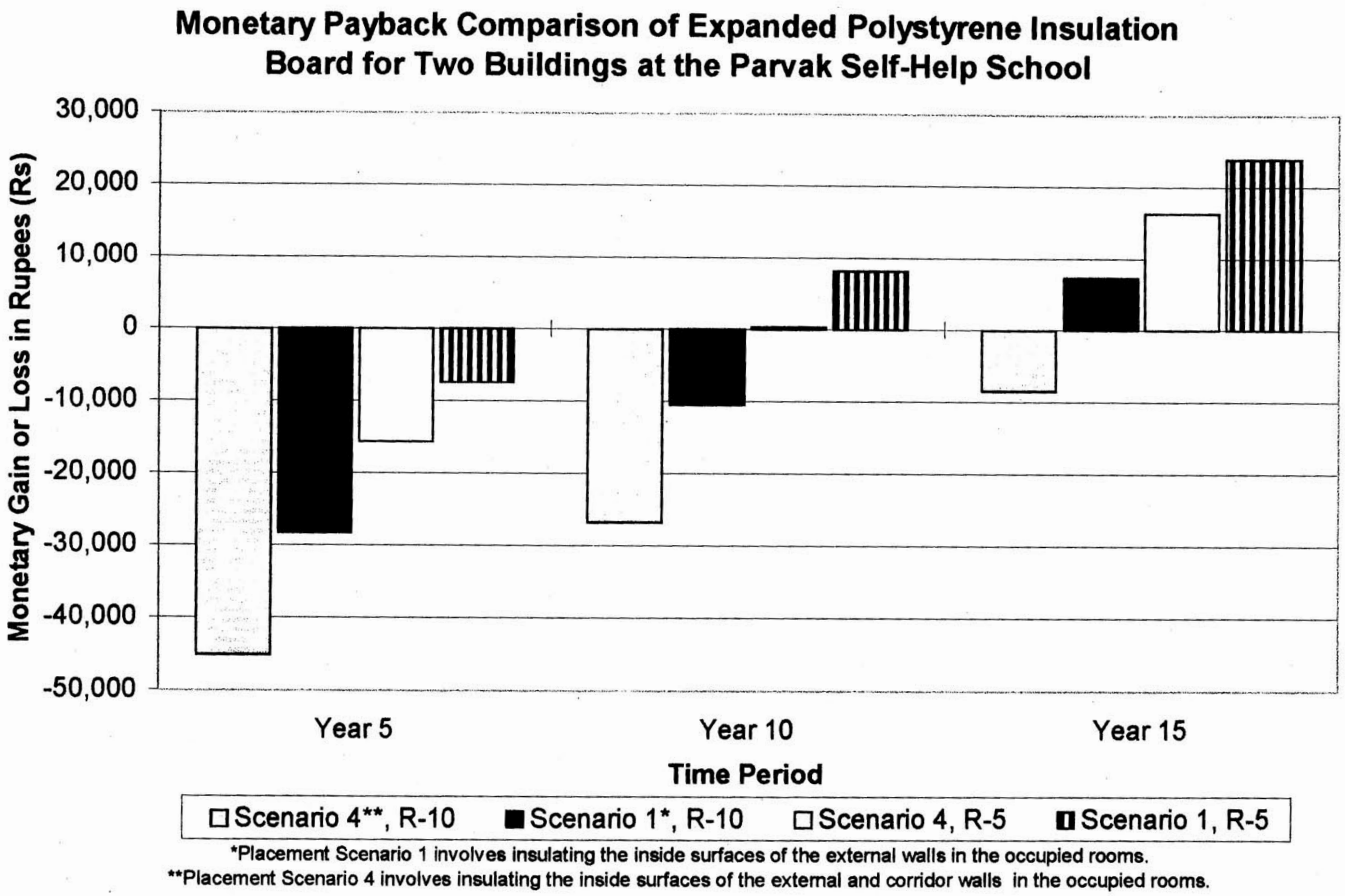


Figure 9-15. Cumulative monetary payback comparison of four insulation strategies with expanded polystyrene for two buildings at the Parvak school

Please note these estimations neither account for inflation nor discount for a standard interest rate on the investment.

Figure 9-15. *Cumulative monetary payback comparison of four insulation strategies with expanded polystyrene insulation board for two buildings at the Parvak school over five, ten, and fifteen year periods.*

After five years, none of the alternatives have reached the break even point. If expanded polystyrene is the chosen insulation material, then Scenario 1, insulating the inside surfaces of the external walls, is the better choice. Once again these estimations neither account for inflation nor discount for a standard interest rate on the investment.

Figure 9-16. *Impact of classroom occupancy on the yearly heating requirements for one building at the Ghakuch, Ahmedabad, and Parvak Self-Help schools.*

This graph highlights the importance of the internal gains from the students to the overall heating requirement of the school. Each person is modeled as generating 70 watts of sensible heat and 57 Watts of latent heat. The two Ghakuch simulations show how by adding 14 more people per classroom, the heating energy requirement can be reduced by 33%. When the occupancy of Parvak is reduced by 14 people per classroom, the difference in heating-energy consumption between the Parvak and Ghakuch shrinks from 51% to 15%. However, overcrowding is not a suitable answer to the problem of reducing heating energy load. A relatively large number of people in a given space will indeed reduce the need for auxiliary heat, and it is reasonable to take advantage of body heat by designing class rooms that are modest rather than cavernous in size and by making full use of available space. However, the need for fresh air may constrain energy savings by prompting occupants to open windows even in cold weather. Air quality decreases with each additional person when airflow rates are constant and an environment that is warm but contaminant-rich is an undesirable outcome. ASHRAE Standard 62-89 specifies that in a school classroom, there should be 15 liters per second of fresh air per person. For the Ghakuch school with an average of 21-25 people per classroom, the fresh air requirement corresponds to approximately 9 air changes/hour. In the tests we conducted during site surveys, using a door-mounted, calibrated fan or "blower door," we measured an average infiltration rate of 1.2 air changes/hour, see Chapter 7 for details related to this calculation. Nevertheless, in the occupant surveys the teachers generally stated the air quality was neutral, neither good nor bad. Except for the summer passive window ventilation analysis, the simulations incorporate the measured air infiltration rates.

Figure 9-17. *Danyore annual heating energy requirement under alternative scenarios.*

Due to its uninsulated, flat roof original construction, it is important to insulate both the ceilings and the external walls of the occupied rooms. These savings do not discount any amount for the cellulosic material (wood, straw, etc.) that might be used to manufacture the insulation. These results show benefits on the order of 76% for the scenarios with 0.88 m^2K/W (5.0 hr $ft^2\,{}^\circ F/Btu$, or R-5) of insulation and 87% for the scenarios with 1.76 m^2K/W (10.0 hr $ft^2\,{}^\circ F/Btu$, or R-10). However, these results are the least accurate of all the schools due to a less precise simulation input file. There are 11 radial classrooms and a central block of rooms in this pre-R&D design. Rather than model the entire school we chose to model four representative zones: three of the classrooms and one corridor. The results of the simulation for this portion of the building were then multiplied by 3.67 to arrive at an overall estimate for the heating energy requirement of the entire school. One problem is that for the insulated scenarios, the heating requirement for the three rooms was often less than the 0.001 gigajoule sensitivity of the simulation package. Therefore, the simulation indicated no heating energy requirements for the months of October, November, and March in these scenarios.

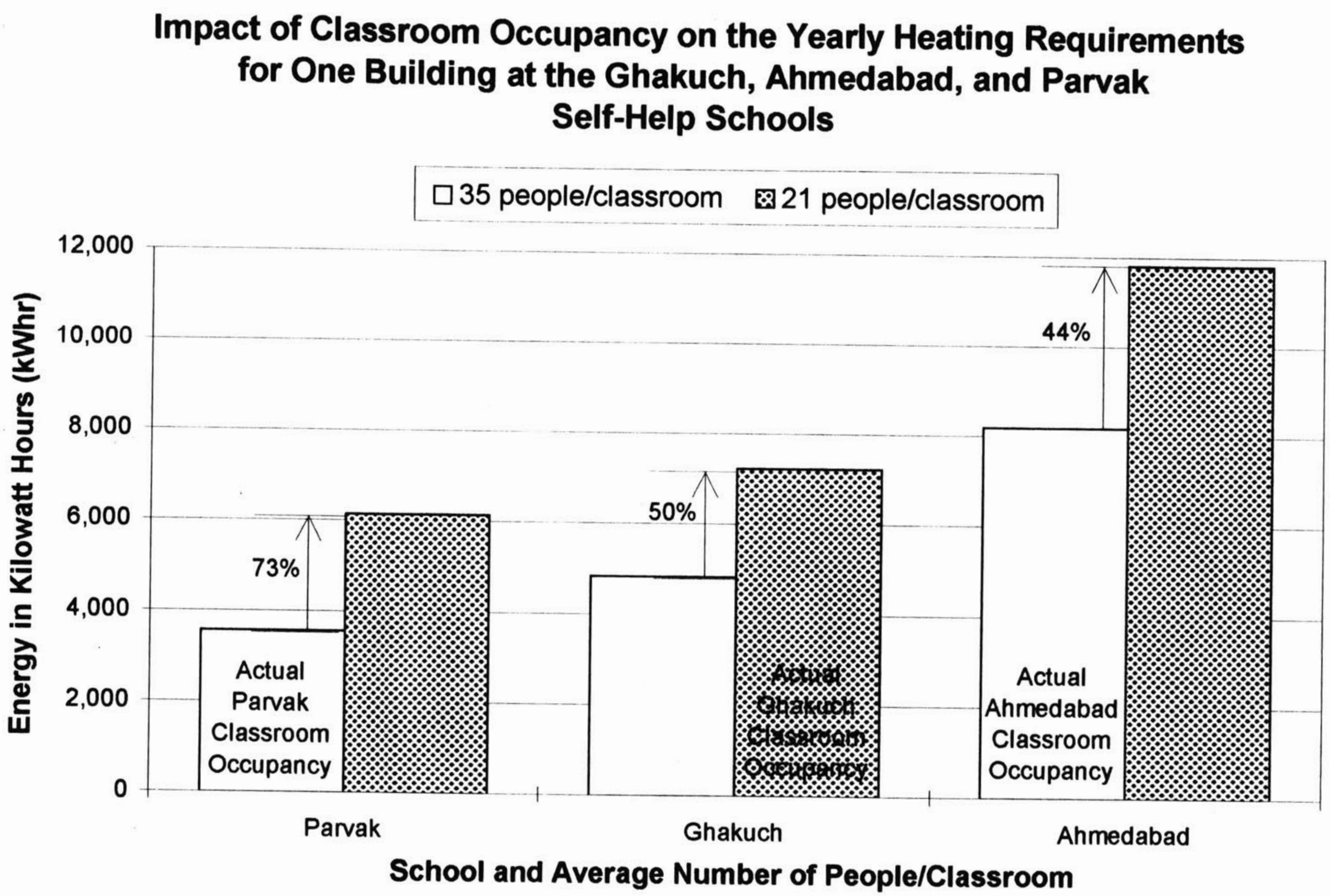


Figure 9-16. Impact of classroom occupancy on the yearly heating requirements for one building at the Ghakuch, Ahmedabad, and Parvak schools

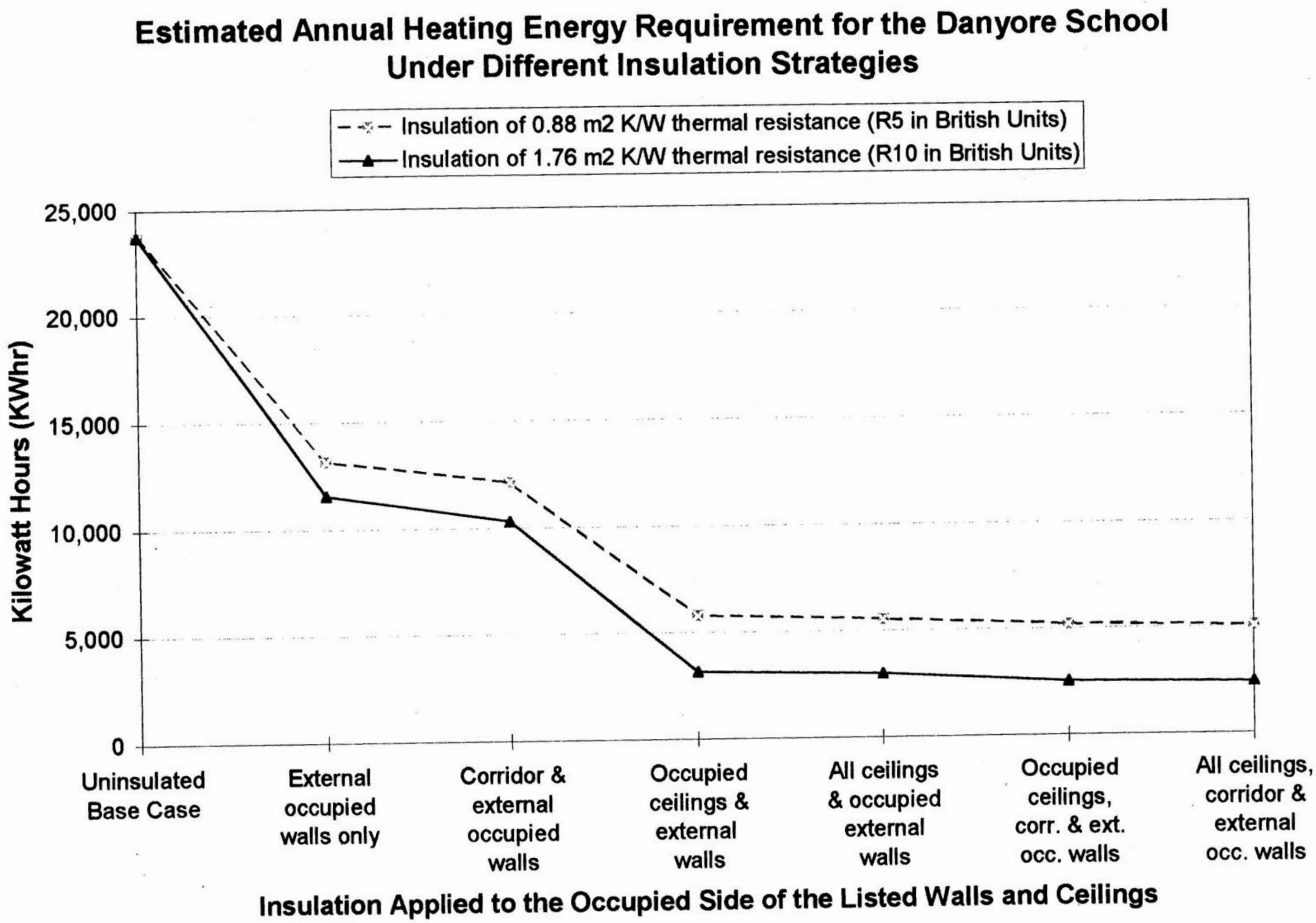
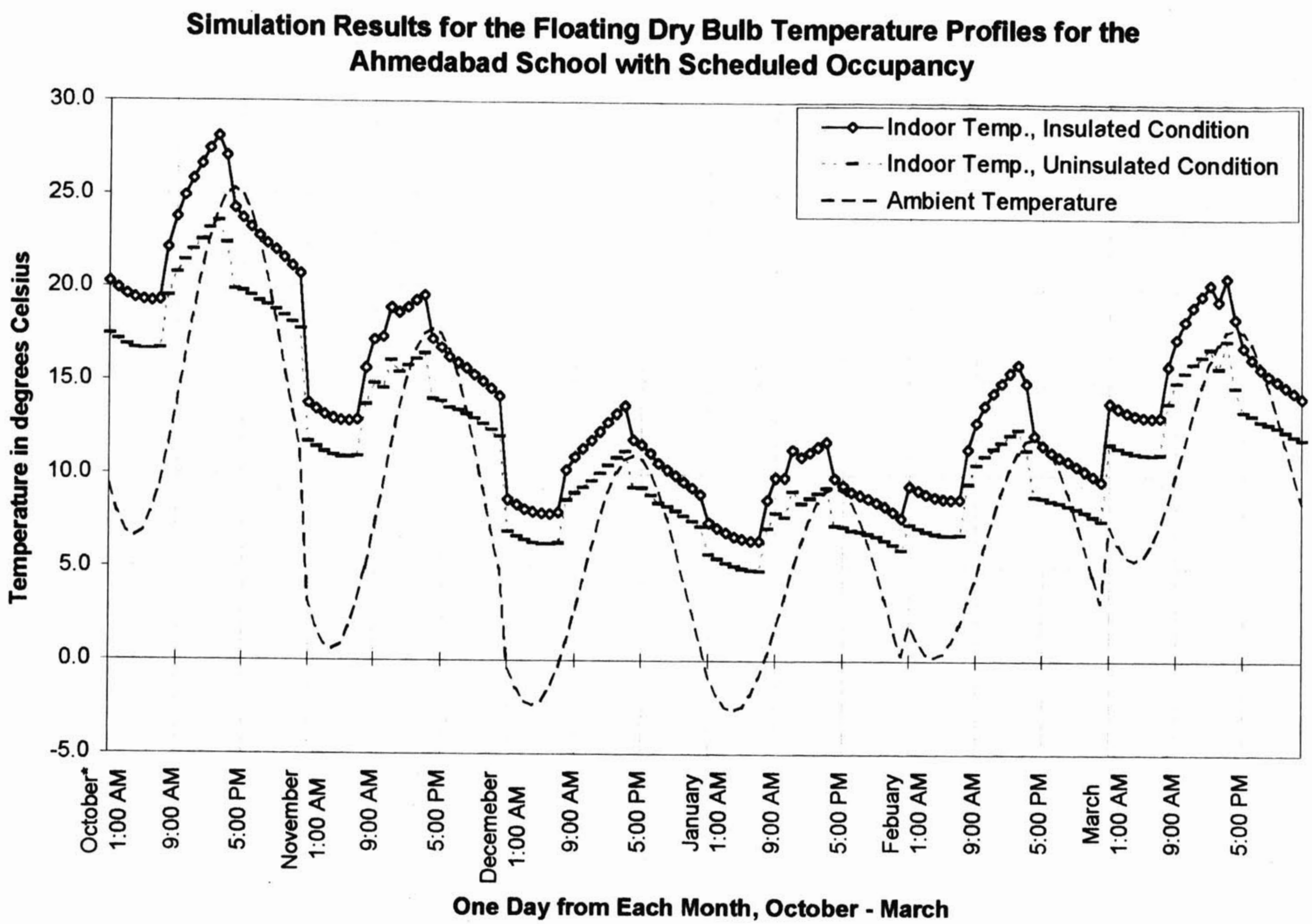


Figure 9-17. Danyore annual heating energy requirement under alternative scenarios.



*These simulations do not account for window ventilation effects that can reduce the maximum indoor air temperature.

Figure 9-18. Simulated floating temperature profiles for the Ahmedabad school.

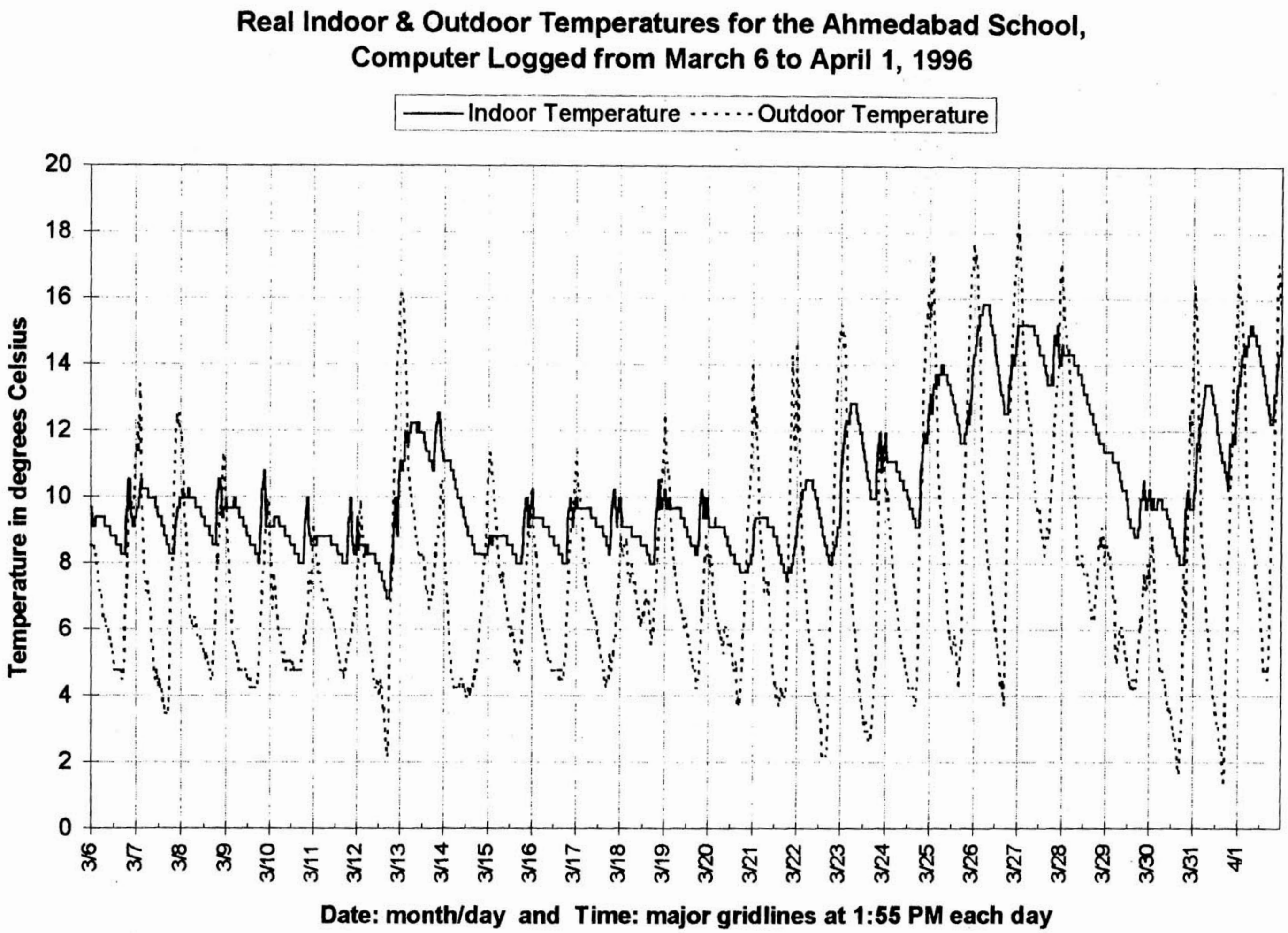


Figure 9-19. Real floating temperature profiles for the Ahmedabad school

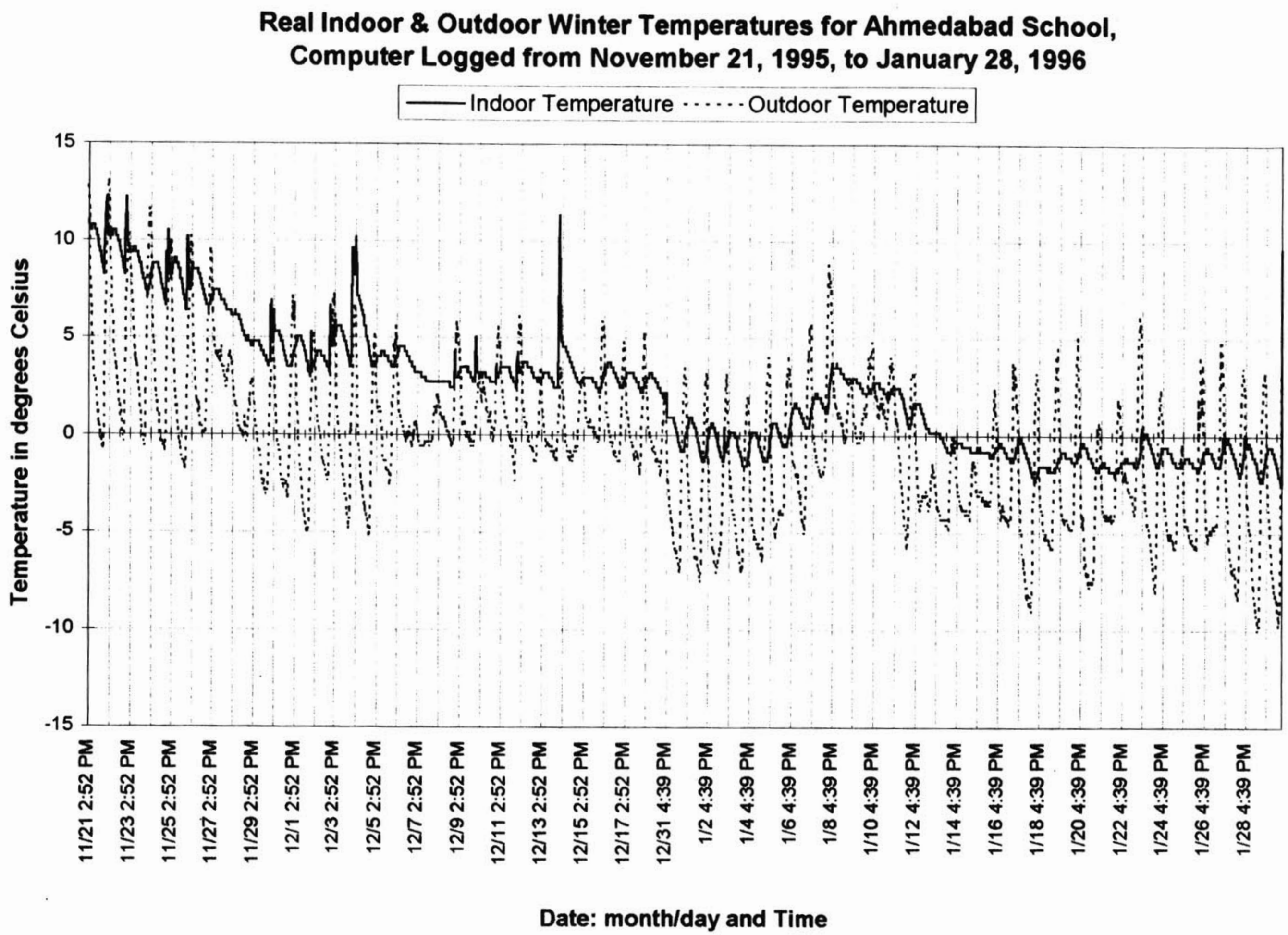


Figure 9-20. Actual floating temperature profiles for the Ahmedabad school

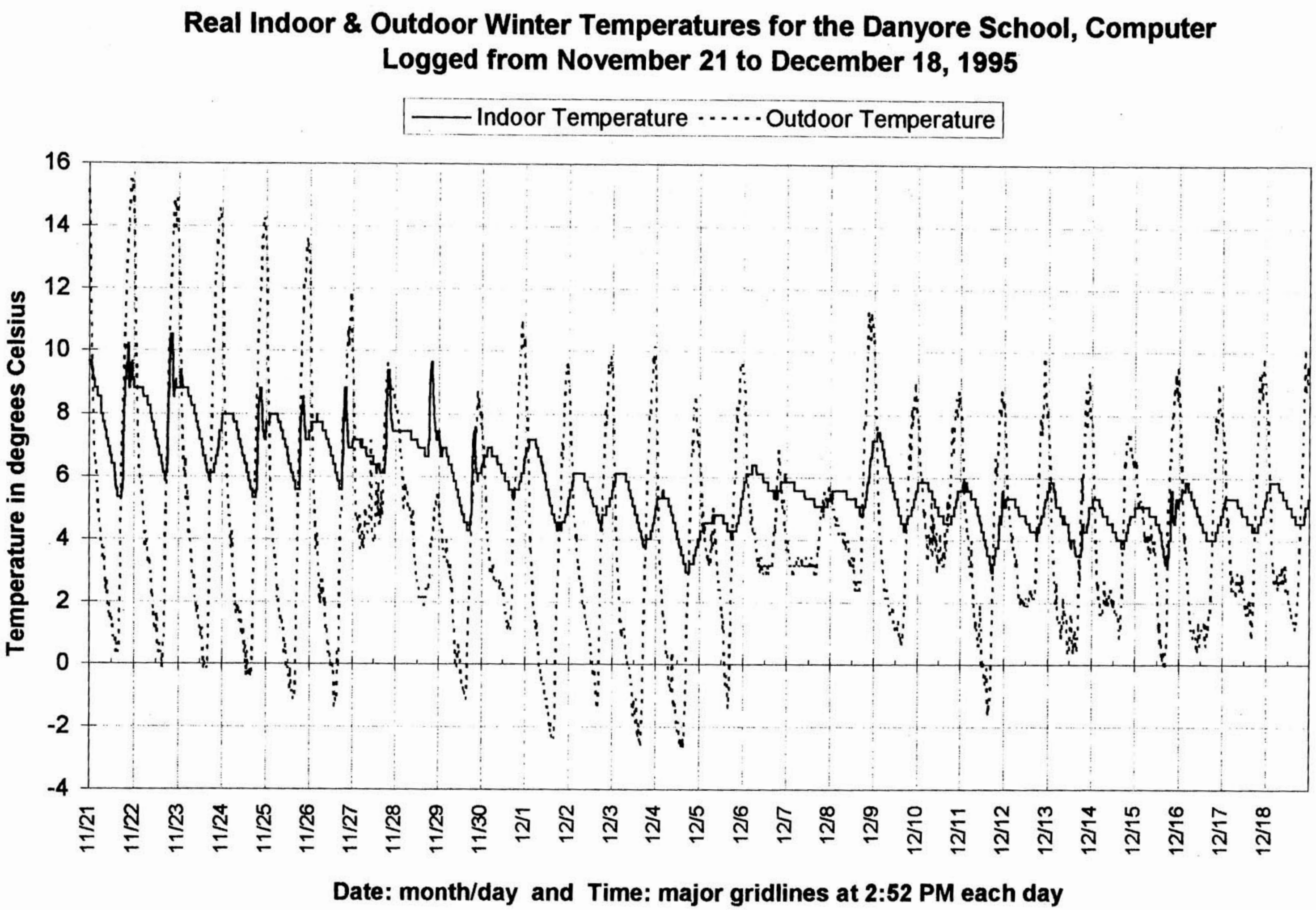


Figure 9-21. Actual floating temperature profiles for the Danyore school

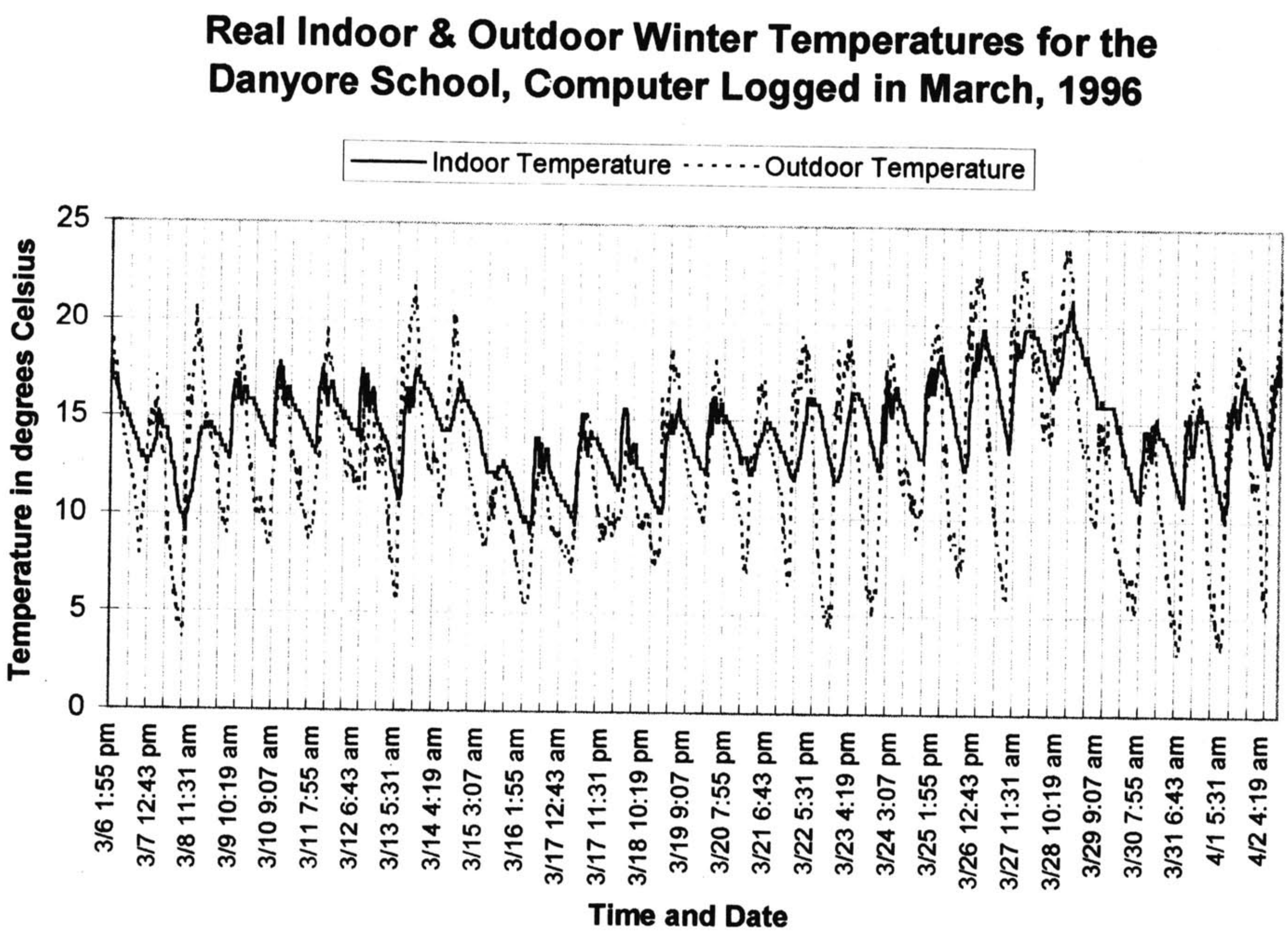


Figure 9-22. Actual floating temperature profiles for the Danyore school

Figure 9-18, Figure 9-19, Figure 9-20, Figure 9-21, and Figure 9-22. *Simulated and actual floating temperature profiles for the Ahmedabad and Danyore schools.*

These figures give a good description of the problem of winter indoor temperatures that are simply too cold. Temperature data was collected on-site with compact temperature loggers. The placement and use of these devices is fully explained in the Section 6.2.1.

Measured data for Ahmedabad, in Figure 9-19, show a smaller indoor-outdoor temperature difference in January than do the simulations for the uninsulated school, Figure 9-18. Accompanying the smaller temperature difference is a discernible phase shift, with indoor temperature peaks and valleys later in the day than outdoor extrema. The damping and the phase shift indicate that more heat is stored in the walls, floor and roof of the school than simulations would indicate.

Figure 9-23. *Simulations of the insulated and uninsulated cases with the windows open all of the time for Ahmedabad during the month of August.*

The occupancy schedule for the Ahmedabad school in these simulations is 8 AM to 3 PM. Opening all of the windows during the summer months raises the building's air infiltration rate from 1.9 air changes per hour to 52.8. To calculate the infiltration rate with the windows open, the building's effective leakage area was increased in proportion to the window area, see Chapter 7 for details of the natural infiltration rate calculations. The chart shows that in this condition, there is very little difference in building thermal performance between the insulated and uninsulated cases. The proposed optimal, summer occupancy schedule is 6 am to 1 pm. This schedule mitigates the impact of the hottest hours of the day.

Figure 9-24 *Simulations of insulated and uninsulated cases with improved climate management during August.*

Optimal climate management includes shading of the southern facing windows for Ahmedabad. The optimal schedule is a strategy that calls for opening the windows are fully from 9 PM to 10 AM and closing them completely from 10 AM to 9 PM. This strategy maximizes nighttime cooling effects and minimizes the large, mid-day, heat transfer from the outdoor environment. It also calls for a summer occupancy schedule of 7 AM to 2 PM. However, it appears from the simulation results that the school will be too hot during the 1 PM to 2 PM hour. Therefore an occupancy schedule of 6 AM to 1 PM is proposed. Three other interesting results are shown in this figure. The first is that there is no improvement in indoor temperature resulting from a substitution of granite walls in place of the hollow core, concrete block walls for the insulated wall scenarios. The second is that a reduction in the occupancy level from 35 to 21 people per classroom results in about a 2°C decrease in indoor temperature at 2 PM. The third is that the uninsulated scenario gives better summer performance than the insulated scenario with shades on the south facing windows. This suggests that the quantity of internal heat generation that is absorbed by the thermal mass of the uninsulated walls and ceilings is greater than the quantity of solar energy rejected by the shades on the southerly windows.

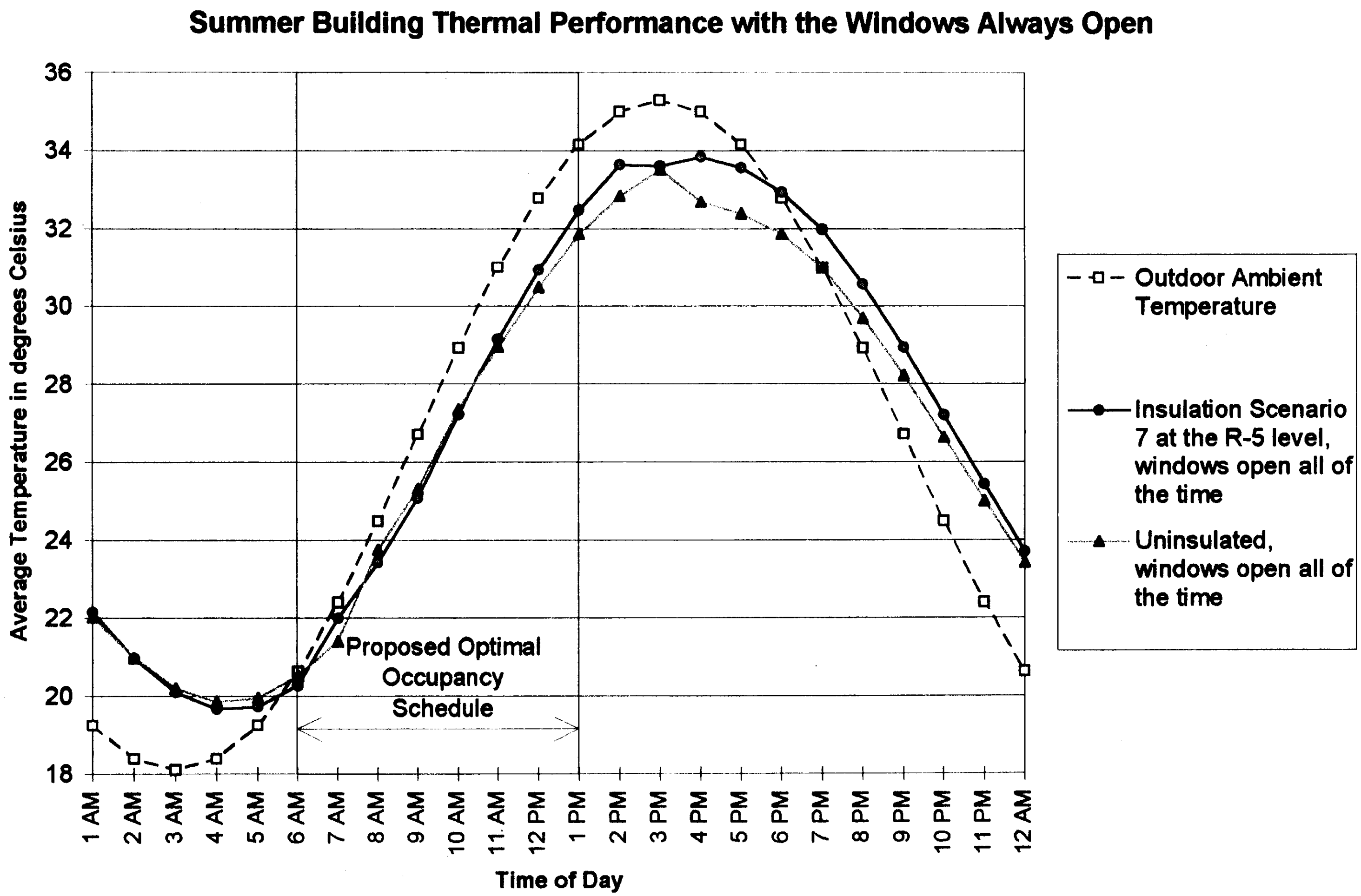
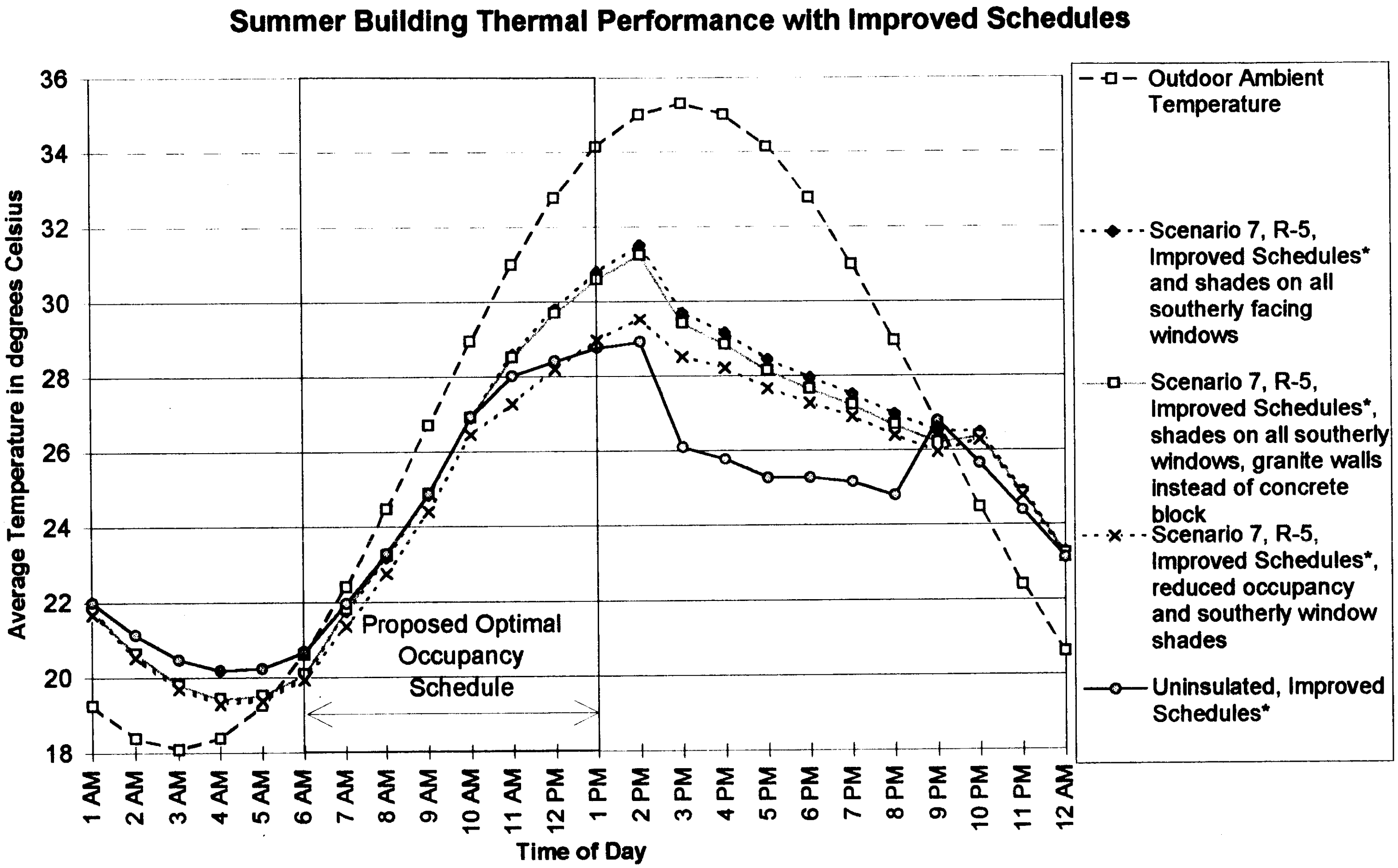


Figure 9-23. Simulations of the insulated and uninsulated cases with the windows open all of the time for Ahmedabad during August



*Improved Schedules is strategy of nighttime ventilation and shifted occupancy schedules where the windows are fully opened from 9 PM to 10 AM and fully closed from 10 AM to 9 PM, using a summer occupancy schedule of 7 AM to 2 PM.

Figure 9-24. August simulations of Ahmedabad for insulated and uninsulated cases, Improved Schedules, and shading of the southerly windows*

10. Improving Building Thermal Performance

10.1 Economic Outlook

Cost data presented in this report indicate that material and labor costs for the installation and plastering boost the overall costs, and therefore the payback periods, by about 25% for the lesser amount (R-5) of polystyrene insulation and 14% for the greater amount of polystyrene (R-10). This extends the polystyrene break-even periods to about 4.4 and 7.1 years for Scenario 1 at Ghakuch. For straw insulation, the overall costs are increased by 42% for the lesser amount of insulation and 26% for the greater amount; these percentage increases are constant across the different insulation placement scenarios. The break-even periods are then stretched to 2.4 and 3.7 years for Scenario 1 with straw insulation. Clearly, fixed costs for plastering make the economics relatively more attractive to apply thicker layers of insulation. The time to break even is defined as the point when the equivalent cost of the energy savings from the building's improved thermal performance is equal to initial cost of the project. *Figure 10-1* and *Figure 10-2* summarize the break-even periods for two optimal insulation placement scenarios at each school using straw insulation material and expanded polystyrene respectively.. The results are given at both the 0.88 $m^2 K/W$ (5.0 hr ft^2 °F/Btu, or R-5) and the 1.76 $m^2 K/W$ (10.0 hr ft^2 °F/Btu, or R-10) insulation quantity levels. For each school, the break even time is charted for the insulation material itself as well as the combined material, installation, and surface finish costs. Please note these estimations neither account for inflation nor discount for a standard interest rate on the investment. Because of this limitation, the projections presented here may be inflated over the actual returns. In Section 7.3 the economic assumptions and the potential impact of the manufacturing labor costs on the analysis are discussed. Although the labor costs were not considered in the payback analysis, the worst case scenario points to a 24% increase over the material cost. Please note that even with the addition of these labor cost estimates, the straw-MDI boards are still 48% below the cost of expanded polystyrene rigid insulation. As previously noted, past experience with the Self-Help Schools suggests the community members may be willing to perform the labor without monetary compensation.

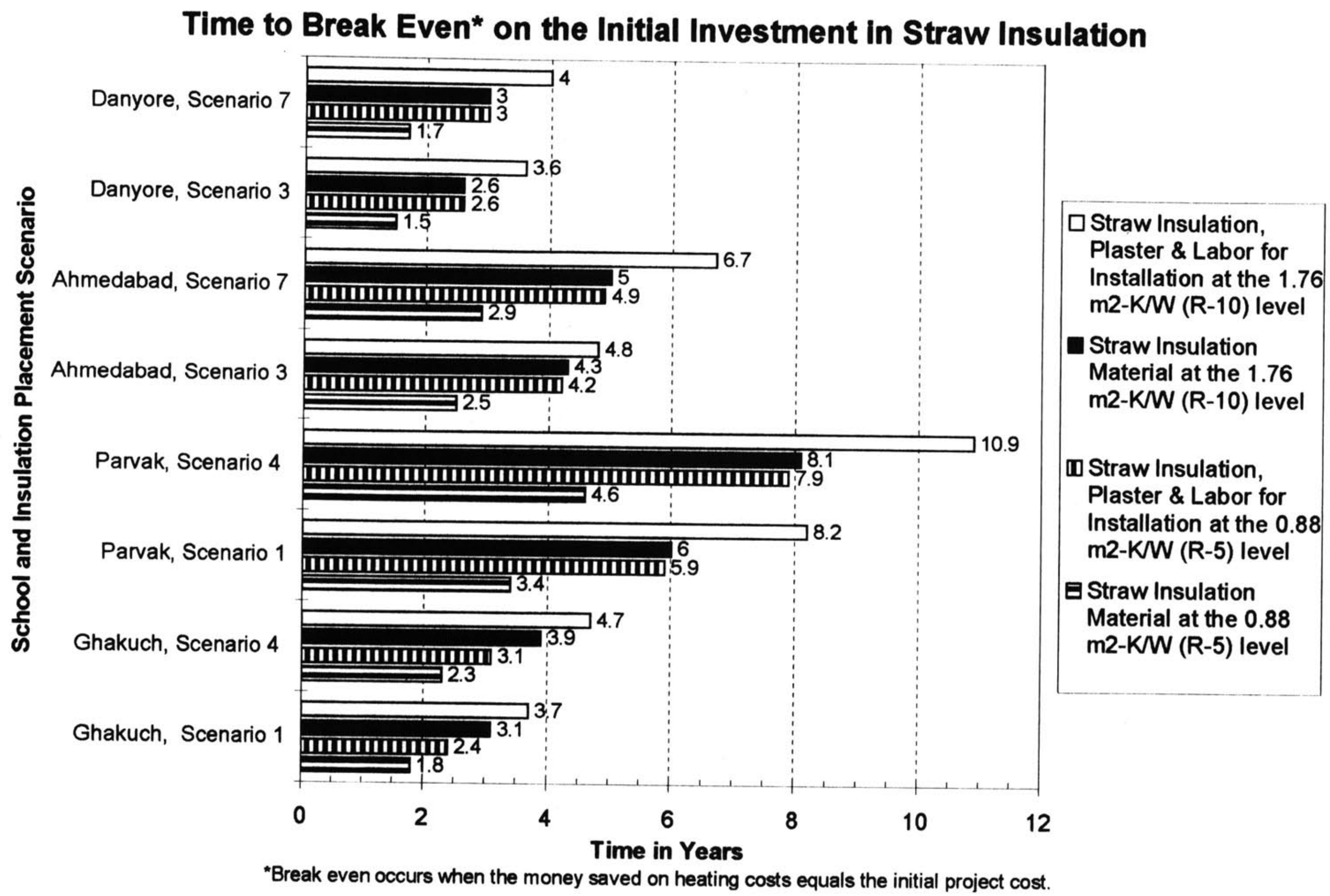


Figure 10-1. Summary of time to break even on the initial investment for two preferred polystyrene insulation placement strategies at each school

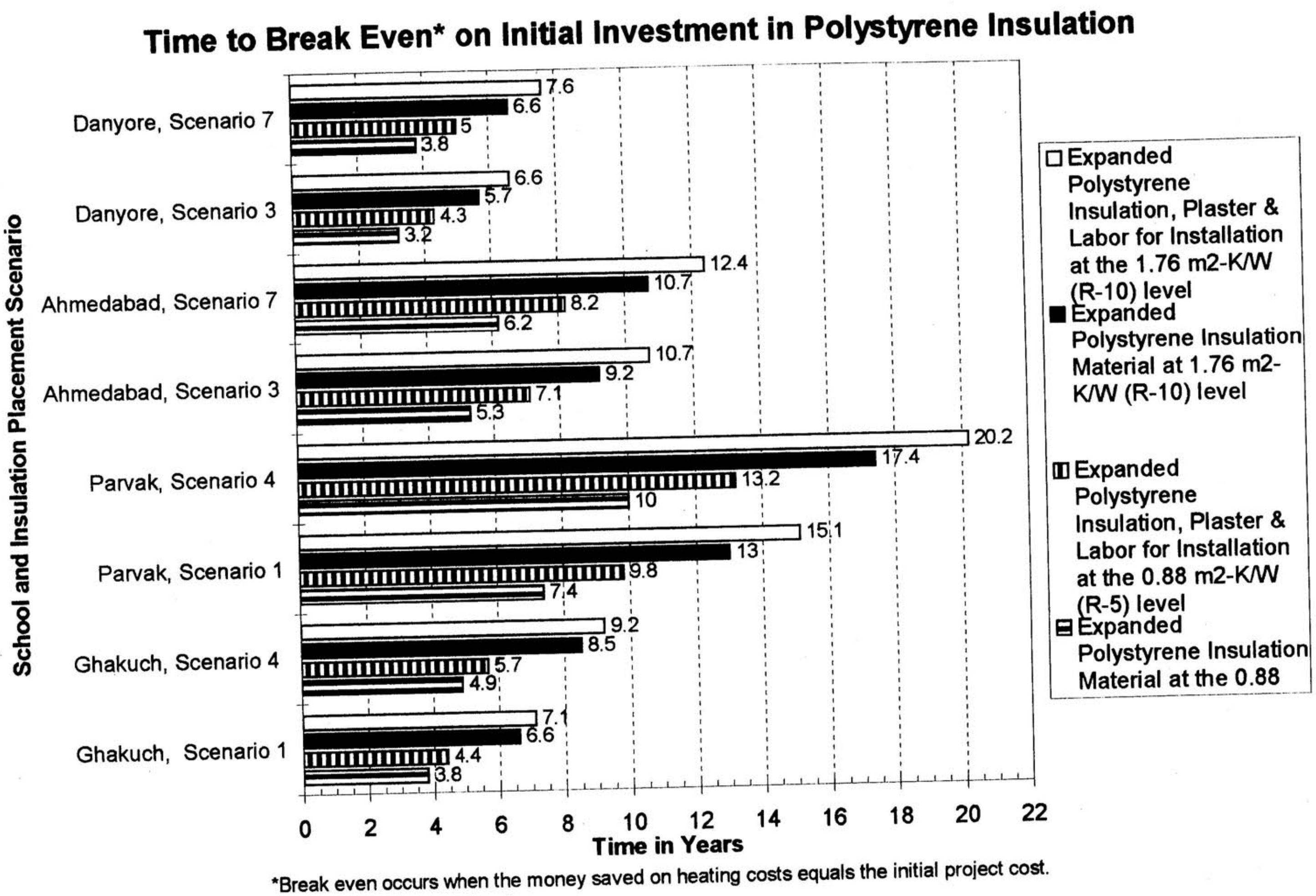


Figure 10-2. Summary of time to break even on the initial investment for two preferred polystyrene insulation placement strategies at each school

10.2 Energy and Wood Resource Considerations

The percentage energy reductions over the baseline conditions for the four schools are summarized in Table 10-1. The listed heating energy requirement does not account for the energy conversion efficiency of the heating device. For example, if stoves of 50% conversion efficiency are used, the actual fuel requirements will be twice the heating energy requirements listed in the table. Scenario 1 with an insulation level of 0.88 m^2 K/W (5.0 hr ft^2 °F/Btu, or R-5) yields heating-energy reductions of 49% and 55% for the Ghakuch and Parvak schools respectively. The break-even period for Ghakuch is 1.8 years for straw insulation and 3.8 years for expanded polystyrene insulation. With Scenario 1, using the larger quantity of insulation level, 1.76 m^2 K/W (10.0 hr ft^2 °F/Btu, or R-10), expands the energy reductions to 57-62%. The tradeoff is that the larger insulation quantity also extends the break-even period form 1.8 years to 3.1 years for straw insulation and from 3.8 years to 6.6 years for expanded polystyrene.

School	Baseline condition heating energy requirement for 1 building	Percentage energy reduction (%) over the baseline condition for the 0.88 m^2 K/W (R-5) and the 1.76 m^2 K/W (R-10) levels of insulation Insulation Placement Scenario						
	kW-hours	1	2	3	4	5	6	7
Ghakuch	7,245	49/57	33/38	49/59	54/62	55/62	55/63	55/63
Ahmedabad	8,216	37/44	25/30	67/78	41/47	40/48	67/76	68/79
Parvak	3,564	55/62	39/45	51/62	56/64			52/63
Danyore	23,735	45/51		76/87	49/57			78/89

Table 10-1. Summary of percentage reductions in heating energy due to installation of thermal insulation at the R-5 and R-10 levels for one building at each school.

Although the cumulative monetary savings for the R-10 insulation alternatives are significantly lower at the 5-year time period than the R-5 alternatives, they generally compare much better at the fifteen year period. Indeed, if a longer payback period is considered, the savings for the R-10 alternatives will accumulate faster than for the R-5 alternatives. For Scenario 4, the percentage savings in terms of the heating energy requirement are slightly higher than for Scenario 1 and the payback periods are slightly longer. Again, the placement scenarios with more insulation material, such as Scenario 4, appear increasingly attractive as time progresses.

Scenario 3 with an insulation level of 0.88 m^2 K/W (R-5) yields heating-energy reductions of 67% and 76% for the Ahmedabad and Danyore schools respectively. The break-even period for the Scenario 3, R-5 strategy at Ahmedabad is 2.5 years for straw insulation and 5.3 years for expanded polystyrene insulation. When the material and labor costs for plaster and installation are included, these break-even payback periods are lengthened to 4.2 years for straw insulation and to 7.1 years for polystyrene.

Scenario 7 with an insulation level of 0.88 m^2K/W (R-5) yields heating-energy reductions of 68% and 78% for the Ahmedabad and Danyore schools respectively. The break-even period for the Scenario 7, R-5 strategy at Ahmedabad is 2.9 years for straw insulation and 6.2 years for expanded polystyrene. When the material and labor costs for plaster and installation are included, these break-even periods are lengthened to 4.9 years for straw insulation and to 8.2 years for polystyrene.

In terms of savings in wood resources, Table 10-2 summarizes the projected cumulative savings in wood resources after a 10 year period. These numbers are based on 250 schools of the given school type being insulated to the lowest level of the recommended insulation scenarios for that school type. A range of 1.7 million kilograms to 4.9 million kilograms is projected.

School Type	*Projected wood savings over 10 year period for 250 schools of the given type*
Ahmedabad	4.9×10^6 kilograms
Ghakuch	3.2×10^6 kilograms
Parvak	1.7×10^6 kilograms

Table 10-2. Projected wood resources savings if replicated by 250 schools

10.3 Thermal Performance Tradeoff for Places with Hot Summers and Cold Winters

A thermally massive wall is a wall that has a large capacity for heat storage. The effect of this mass is to dampen the daily fluctuations of the indoor air temperature. During the winter, we want to maximize the rise the classroom temperature rise supplied by the occupants. A preliminary round of simulation data compared insulating the inside surface of the walls with insulating the external surface of the walls. These results indicated that significant wintertime improvements could be achieved by placing the insulation on the inside surfaces rather than the outside surfaces. This result confirms our expectations that ideally we want to shield the massive walls from the internal heat generation during the winter months. It turns out that the large classes, ranging from 20-45 students, are a very significant source of heat. A second benefit of this method is that the insulation does not degrade over time as quickly as is likely in the case of exterior insulation.

One disadvantage of this method is that several inches of valuable interior space are lost from each wall surface. Through direct user interviews, it was determined that it is acceptable to sacrifice this portion of the room in return for improved thermal comfort in the winter. Another important consideration is the building's thermal performance during the hot summer months. In this context, we can generalize that we would prefer to apply the insulation to the exterior of the of the building. Exterior insulation shields the mass of the building from the incident solar radiation and the convective heat gains, while exposing it to the internal load from the occupants. However, this generality is tempered by the fact that window ventilation is common practice in these regions and the rest of the world. The act of opening the classroom windows significantly increases the convective heat exchange between the classroom and the ambient environment, thereby reducing the overall benefit of applying insulation to the external surfaces of the building's mass. Indeed, the simulations show that if the windows are open in both an insulated and an uninsulated building, the indoor air temperature profile will be nearly identical. With the relatively large class sizes and small classrooms, opening the windows provides fresh air that is very desirable for the occupants. One additional benefit of this open-window situation is that the slightest of breezes will improve the thermal comfort of the occupants provided that the air temperature is below the human skin temperature of 34 °C. In summer when the ambient air temperature reaches 32 degrees Celsius (generally after 11 AM) and there is no appreciable breeze, closing the windows will improve the occupants' level of thermal comfort. However, if the indoor air then becomes uncomfortable or malodorous, one or more of the windows must be opened once again.

Shading is a very good method of reducing the impact of solar radiation. Applying shade cloth to the either the outside or inside surface of transparent skylights and southerly facing windows of the occupied rooms and the corridors can significantly reduce the solar gains. Another strategy for an area with large diurnal temperature swings is nighttime ventilation. If the outside nighttime temperature is lower than the indoor building temperature, then the strategy of opening up the windows can result in significant nighttime cooling in the summer months. From a combination of nighttime cooling and shading of the southerly facing windows, the simulations predict up to a 5.4 °C reduction in the indoor temperature.

Through interviews at the Danyore school there was a concern expressed about a potential security problem related to leaving the windows open at night. In situations such as this, it may be necessary to install permanently fixed ventilation grills, bars over the windows, rooftop vents, or operable skylight fixtures to address this concern. Since exterior insulation is the favorable method in the summer and interior insulation is preferable in the winter, the ideal might be some type of movable insulation. However, this method requires both a moveable insulation such as a tapestry and a commitment to maintain the insulation. This strategy has not been evaluated in this study and hence is not recommended for current implementation, only as an avenue for further investigation.

Our recommendation for reducing the impact of unwanted heat gains from solar radiation is to develop a strategy involving one or more of the following steps:

1. use of strategically located deciduous trees to shade the building
2. use of local, broad-leafed, summer vine plants in conjunction with a horizontal supporting trellis to provide summer shading of the external surfaces of the building
3. use shade cloth on either the outside or the inside surface of transparent skylights and southerly facing glass windows

4. use a rooftop mounted inorganic shade structure, employing steel reinforcing bar extensions with a white (preferable), red or green, opaque tarpaulin stretched across the frame

Using plants or removable man-made shading devices enables seasonal control of the incident solar radiation on the roof. Ideally the roof is shaded during the summer months and is exposed to direct solar radiation during the winter months. For the galvanized iron roof construction, the solar energy is reflected throughout the entire year, possibly having a negative impact on the building thermal performance during the winter. The reflectivity of the roof surface has not been evaluated here and is recommended as an avenue for further investigation.

The final option for consideration is to shift the school day to an earlier schedule during the hot summer months. In our survey, some schools reported that the summer schedule was indeed shifted to 7:30 AM to 1:30 PM. If early afternoon overheating continues to occur, this schedule could be shifted even earlier to 6:00 AM to achieve greater improvements in thermal comfort during the school day.

10.4 Summary of Recommendations

Thermal insulation can provide large benefits for the Self-Help schools in the Northern Areas and Chitral region of Pakistan. The conclusion of this study is that the best place to install the insulation is on the inside surfaces of the buildings. The conclusion was reached that the differences in school design between the Pre-R&D and the Post-R&D plans were of much less significance than the insulation or lack thereof in the roof construction. For schools of the slanted-roof construction, a substantial quantity of insulation (approximately 150 mm of sirkander grass) is already present in the existing construction. In this study, the Parvak and Ghakuch schools are examples of this type of roof construction. The insulation placement scenarios that provide the best return on the investment for the slanted, insulated roof schools are:

- Scenario 1, insulating all of the external walls of the occupied rooms; and
- Scenario 4, insulating all of the walls of the occupied rooms except those shared with another occupied room.

For schools of the flat, uninsulated roof construction it is extremely important to insulate the ceiling as well as the walls. In this study, the Ahmedabad and Danyore schools are examples of the flat-roof construction. The insulation placement scenarios that provide the best return on the investment for the flat, uninsulated roof schools are:

- Scenario 3, insulating the external walls and ceilings of the occupied rooms; and
- Scenario 7, insulating the ceilings, the external walls, and the walls shared with the corridor.

It can be generalized across the different school designs and construction techniques that insulating to the higher level of 1.76 m^2 K/W (10.0 hr ft^2 °F/Btu, or R-10) makes heating the building an easier process and leads to greater overall savings of natural resources. Problems with summer overheating, if any, can be addressed through shading the windows, walls, and roofs with either plants or man-made structures such as window shades, coloring the roof with a white pigment (do not paint the highly reflective, corrugated galvanized iron roofs), nighttime ventilation, and shifting the hours of occupancy to avoid the hours of away from the hours between 1 pm and 5 pm. In schools that are currently unheated or under-heated, improving the students' level of thermal comfort will facilitate their ability to study and to pay attention. Improving the building's thermal performance will make it possible to reduce the length of the winter break, when schools are now closed in part because they are too cold inside. To what degree a school is insulated may depend on the economic resources of the community or supporting organizations, and the value placed on being able to make better winter use of the school buildings. Our economic analysis was based on costs today without regard to inflation and scarcity of resources. In the years ahead, it may be that the relative scarcity of fuel wood causes the price of wood to escalate faster than the general inflation rate. This situation would reduce the break-even time periods and increase the cumulative savings for all the scenarios presented here.

MIT recommends performing a pilot insulation program in order to prove the concepts presented in this thesis and to facilitate the widespread adoption of thermal insulation board in northern Pakistan. It is recommended that a single school initially be insulated to 1.76 m^2 K/W (10.0 hr ft^2 °F/Btu, or R-10). The selected school should be one included in the site surveys, for which temperature baseline data are available. With temperature data and occupant surveys before and after the installation of insulation, there would be a strong basis for an informed assessment of the benefits of insulation. The Ahmedabad school is the preferred initial site based on the excellent condition of the school and also because of it experiences a slightly colder winter than Danyore. It is recommended that either expanded polystyrene sheets or prototype straw-based panels be used in the initial demonstration school. Expanded polystyrene is an option for the demonstration site because it is currently available in the Northern Areas and the initial pilot program will not experience any delays resulting from material availability. If there is sufficient interest from the Aga Khan Housing Board for Pakistan, we recommend that further thermal insulation installations aim to use the straw-based material. Depending on the nature of the straw insulation test program, the prototype panels can be made in the US or in the Northern Areas, Pakistan. Major benefits of the straw based insulation are lower cost per unit thermal resistance, use of local resources, use of local labor, and the overall development of the local economic community. More information on the complete straw based insulation system is available in Part I of this thesis.

11. Preparation of the Weather Data for the Gilgit and Chitral Regions

We created two weather files, one describing the three schools in the Gilgit region of the Northern Areas and the other describing the Chitral region. The primary data for the computer weather files was taken from the 30 year (1961-1990) weather record for the Gilgit and Chitral regions published by the Pakistan Meteorological Department. In some cases it was necessary to apply geometrical curve fits to interpolate the data from the given values. The direct normal and total horizontal solar irradiation values were computed using geometric calculations based on the longitude, latitude, and cloud cover data from the weather records. The result of this effort was to create a 24-hour snap shot of a typical day for each month for both of the regions. This typical day was then multiplied by the number of days in the given month to create the weather files for the computer energy simulations. Although the same weather profile was used for each day of the month, the simulations were run for 25 days each month to allow sufficient time for the solutions to the mathematical model of the building performance to stabilize. The thermal capacity of the building materials and the dynamic nature of heat gains and losses contribute to this phenomenon.

11.1 Wind Speed

In the case of wind speed, there was no apparent geometrical curve fit to apply to the data. Graphs of the linear step profiles of the wind speed data for Gilgit and Chitral are given in Figure 11-1 and Figure 11-2.

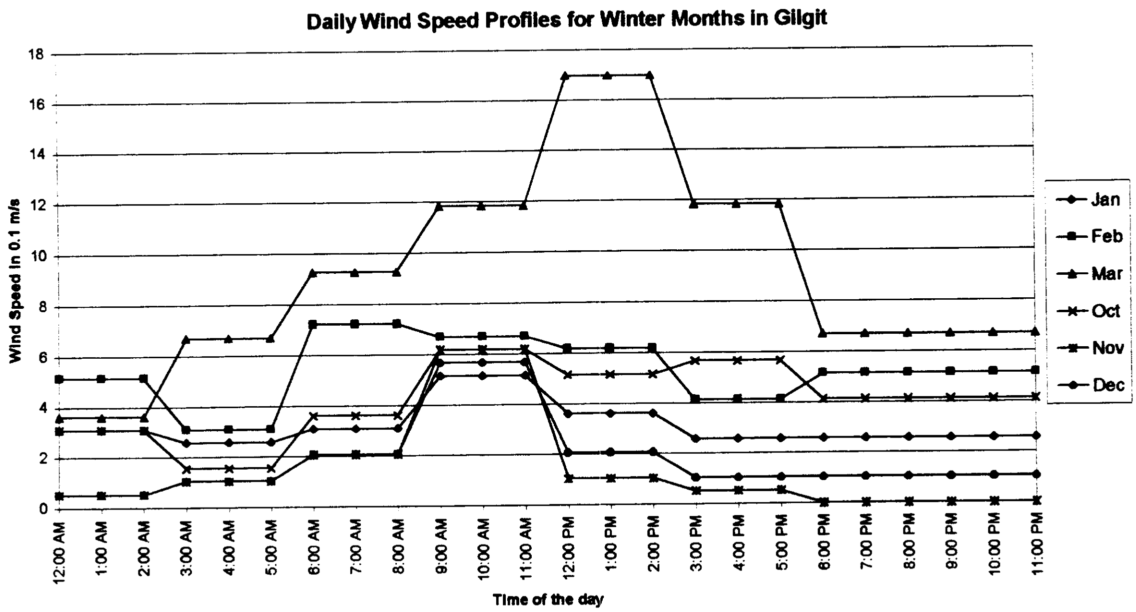


Figure 11-1. Daily wind speed profile for winter months in Gilgit.

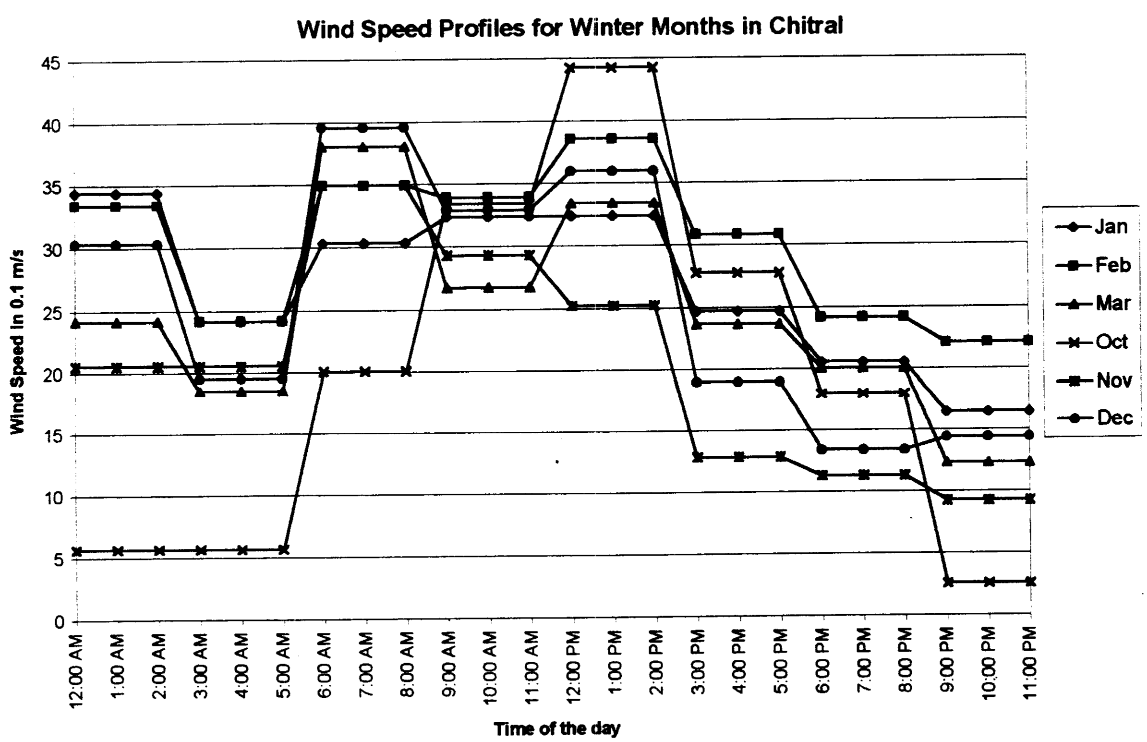


Figure 11-2. Daily wind speed profile for winter months in Chitral.

11.2 Dry Bulb Temperature

The diurnal swings of the ambient dry bulb temperatures can be abstracted as a sine curve. The weather record gave the average daily maximum and minimum values for each month. The hourly points were then generated using the following equations:

$$Hourly\_Variation = \left(\frac{T_{maximum} - T_{minimum}}{2}\right)\sin\left[\left(\frac{2\pi}{24}\right)(Hour - 9)\right]$$

$$T_{hour} = \frac{(T_{maximum} + T_{minimum})}{2} + Hourly\_Variation$$

where:

$Hour$ = the hour of interest (0-24)

T_{hour} = the temperature at that hour

$T_{maximum}$ = the monthly mean daily temperature maximum from the weather record

$T_{minimum}$ = the monthly mean daily temperature minimum from the weather record

$Hourly\_Variation$ = the sinusoidal fluctuation about the mean temperature difference

The results of applying these equations functions to the monthly mean daily maxima and minima dry bulb temperatures for Gilgit and Chitral are given in Figure 11-3 and Figure 11-4 respectively.

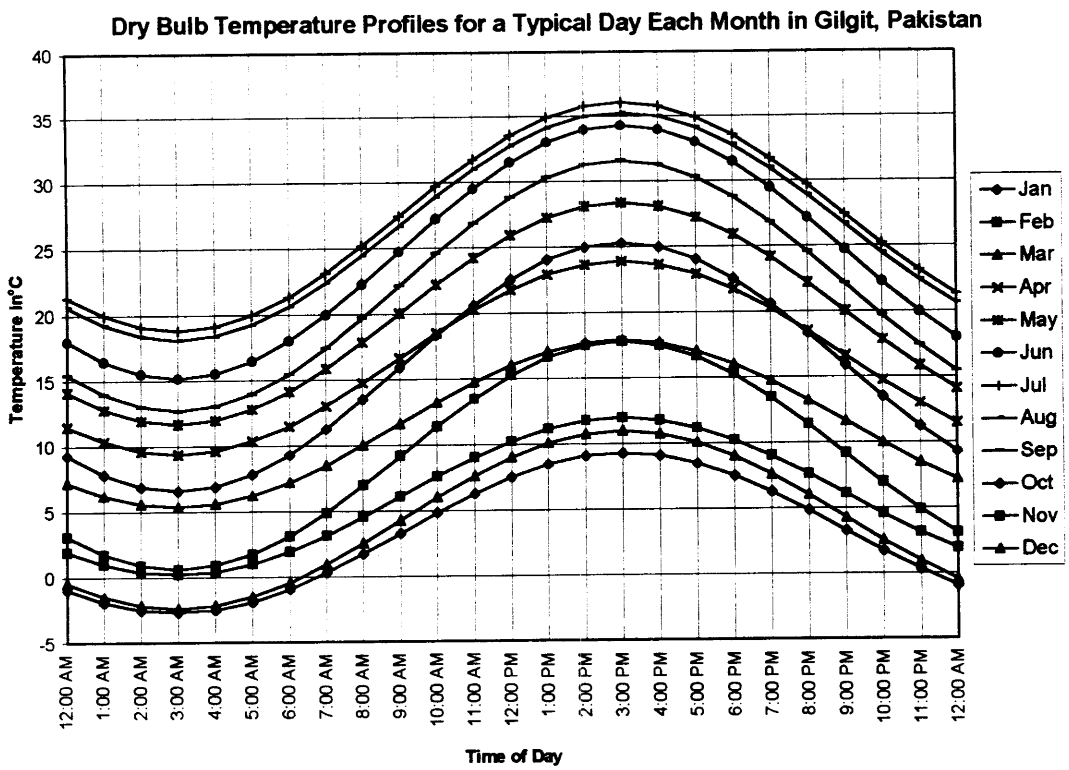


Figure 11-3. Sinusoidal approximations of the average monthly outdoor dry bulb temperature profiles for Gilgit, Pakistan.

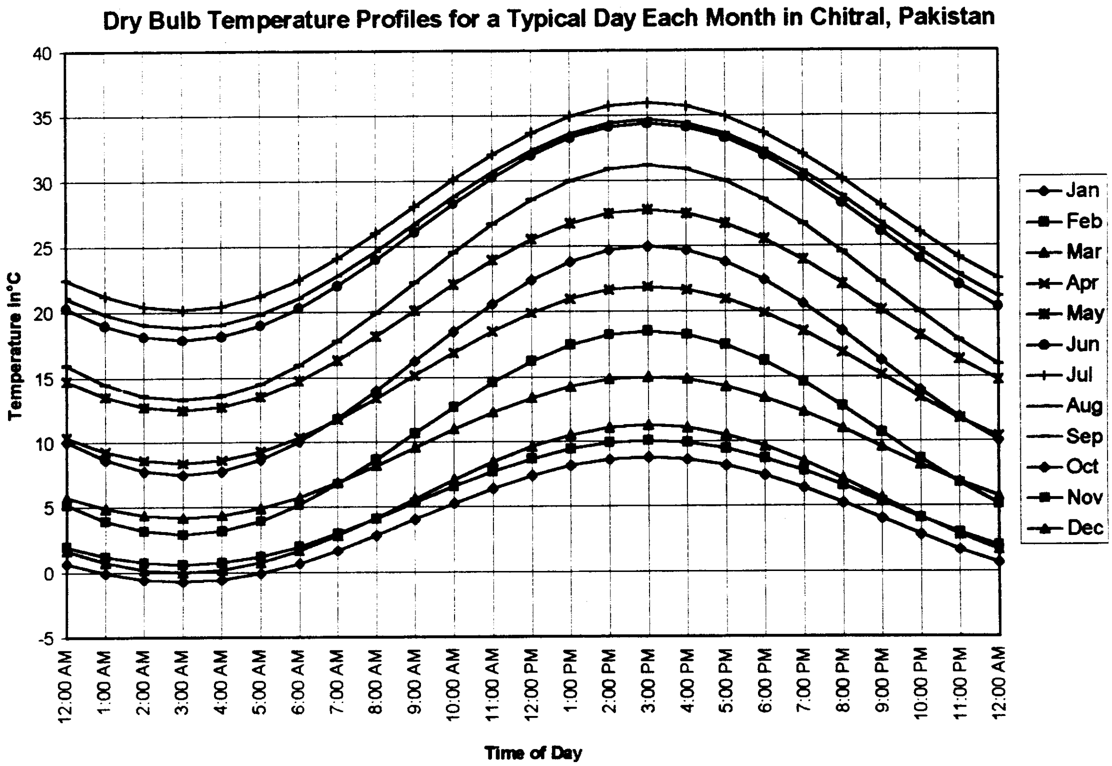


Figure 11-4. Sinusoidal approximations of the average monthly outdoor dry bulb temperature profiles for Chitral, Pakistan.

11.3 Dew Point Temperature

The dew point temperature data was given at midnight, three in the morning and at twelve noon. Three linear equations were used to interpolate this data:

$$T_{dp} = T_{dp,0000} + hour\left(\frac{T_{dp,0300} - T_{dp,0000}}{3}\right), \text{ for 0000 to 0300 hours}$$

$$T_{dp} = T_{dp,0300} + (hour - 3)\left(\frac{T_{dp,1200} - T_{dp,0300}}{9}\right), \text{ for 0300 to 1200 hours}$$

$$T_{dp} = T_{dp,1200} + (hour - 12)\left(\frac{T_{dp,0000} - T_{dp,1200}}{12}\right), \text{ for 1200 to 2400 hours}$$

where:

$T_{dp,0000}$ = dew point temperature at the given hour, 12 midnight in this case

hour = hour of the day in military (0-24)

Graphs of these linear interpolations are given in Figure 11-5 and Figure 11-6. During the winter months, the dew point only falls above the freezing point during the month of October in both Gilgit and Chitral. This is indicative of the very dry and cold winter conditions in these regions.

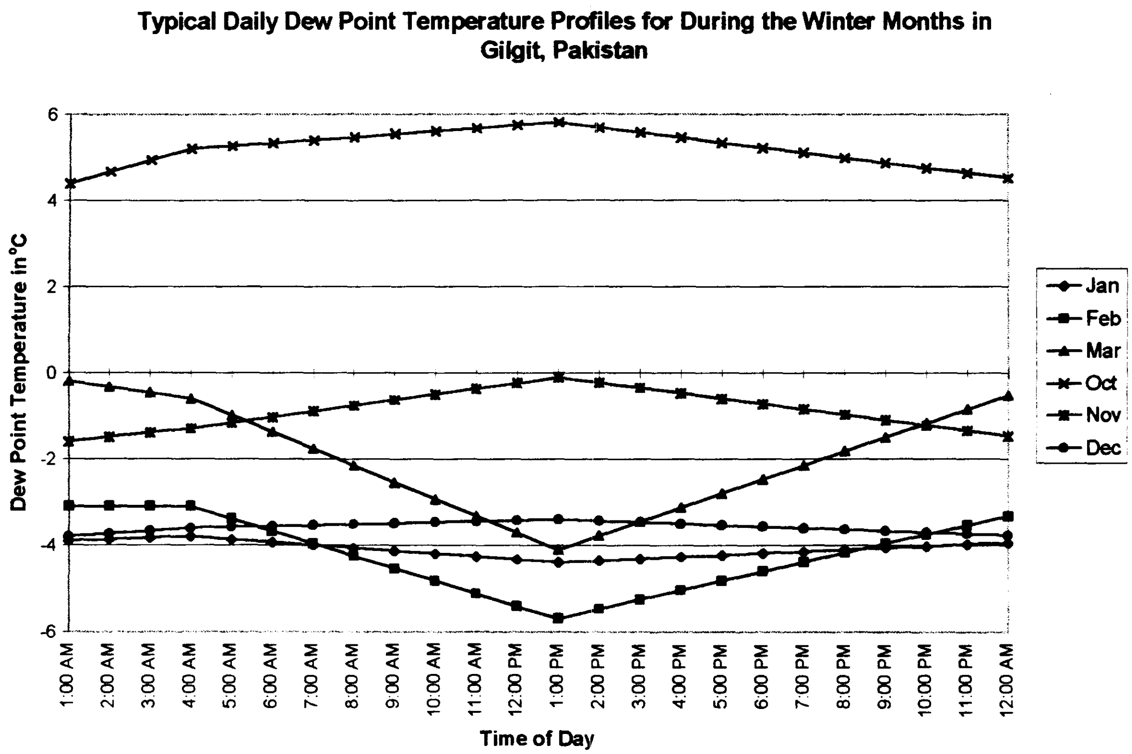


Figure 11-5. Dew point temperature profiles for Gilgit, Pakistan

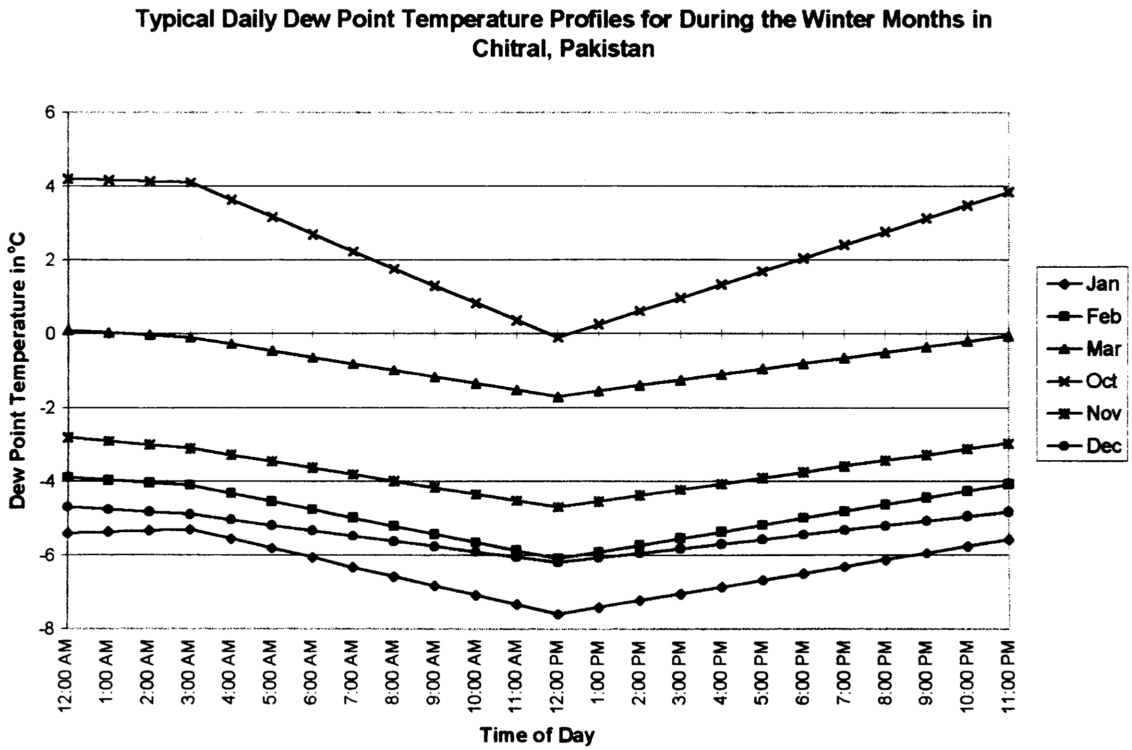


Figure 11-6. Dew point temperature profiles for Chitral, Pakistan

11.4 Solar Radiation

The position of the sun with respect to a given location can be found using geometric calculations based on date, time, and latitude. The time is translated to an hour angle, *h*. The hour angle is the angle between the projection of the earth-surface location onto the equatorial plane and the projection of a line connecting the centers of the earth and sun on the equatorial plane. The date is characterized by a declination angle, *d*. The declination angle is defined as the angle between a line connecting the centers of the earth and sun and the projection of that line on the equatorial plane. These parameters are shown in Figure 11-7 for a point, *P*, on the earth's surface. The latitudes used for the Gilgit and Chitral solar data are 35 degrees 55 minutes North and 35 degrees 51 minutes North respectively.

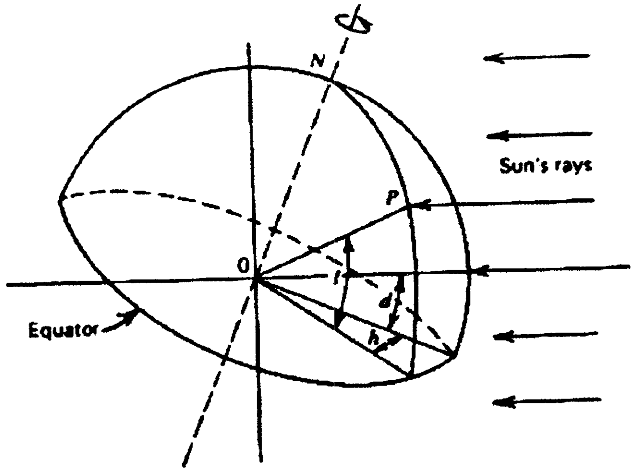


Figure 11-7. Diagram of the latitude, hour angle, and declination angle [McQuiston and Parker 1994]

The solar altitude, β, is defined as the angle of the sun above the horizon. By analytic geometry it can shown that the solar altitude angle is related to the hour angle, the declination angle, and the latitude, l, with the following equation:

$$\sin\beta = \cos l \cos h \cos d + \sin l \sin d$$

The earth's atmosphere plays a large role in diminishing the intensity of the solar radiation before it reaches the earth's surface. This is due to scattering and absorption from ozone, dust, pollutants, water vapor, and atmospheric pressure. Along with the concentrations of the various particles, the atmospheric depletion of radiation is also dependent on the thickness of the atmosphere through which the sun's rays must travel. This thickness is characterized as the air mass above a given location and can be calculated for practical purposes as the cosecant of the solar altitude angle in radians.

$$Air\_Mass = \frac{1}{\sin\beta}$$

Extraterrestrial radiation refers to the insolation at a location just outside of the earth's atmosphere, at an air mass of zero, before any atmospheric scattering and absorption occurs. The average value for the daily horizontal extraterrestrial radiation, I_o, can be found in tables. The 30-year weather record for Pakistan provides cloud cover data in octals. The following equation was used to calculate the hourly horizontal extraterrestrial radiation, $I_{o,h}$, from the daily average value [Kreith and Kreider 1978]:

$$I_{o,h} = I_o\left(1 + 0.034\cos\frac{2\pi n}{365}\right)(0.9972\cos l \cos d \cos h + \sin l \sin d)$$

where n day number in the year starting from January first and l, d, and h are defined as above. In this study, the weather files describe a typical day for each month extrapolated from the average daily maximums and minimums for that month. For the solar insolation data, the fifteenth day of each month was selected in the calculations.

The quantity of the extraterrestrial radiation that reaches a location on the earth's surface is referred to as the total horizontal radiation. To predict the hourly total horizontal radiation, I_h, Randall and Leonard have developed a correlation on the basis of cloud cover, CC, and air mass, Air_Mass [Kreith and Kreider 1978]:

$$I_h = \frac{I_{o,h}}{100}\left(83.02-(3.847*Air\_Mass)-(4.407*CC)+\left(1.1013*CC^2\right)-\left(0.1109*CC^3\right)\right)$$

The hourly percent of possible sunlight, k_t, is defined as the ratio of the hourly total horizontal radiation to the hourly horizontal extraterrestrial radiation.

$$k_t = \frac{I_h}{I_{o,h}}$$

The direct normal component can also be derived from correlations based on percent of possible insolation, k_t [Kreith and Kreider 1978].

$$I_b = -520 + (1800 * k_t) \quad \text{for } 0.85 > k_t >= 0.30$$
$$I_b = 0 \quad \text{for } k_t < 0.30$$

The hourly diffuse component can then be found by subtracting the direct beam component from the total horizontal:

$$I_{d,h} = I_h - I_b \sin\beta$$

where β is the solar altitude angle [Kreith and Kreider 1978].

The SERI-RES program requires that the weather files include the direct normal solar irradiance, the total horizontal solar irradiance, the ambient dry bulb temperature, the ambient dew point temperature, and the wind speed.

Part III. Appendices

12. SERI-RES Input Files

This section contains a sample weather record and models of the four schools in the form of SERI-RES input files:

1. Sample Weather Record
2. Complete Ghakuch Self-Help School baseline input file
   Listing of alternative insulation scenarios that were simulated
3. Complete Ahmedabad Self-Help School baseline input file
   Listing of alternative insulation scenarios that were simulated
4. Complete Parvak Self-Help School baseline input file
   Listing of alternative insulation scenarios that were simulated
5. Complete Danyore Self-Help School baseline input file
   Listing of alternative insulation scenarios that were simulated

12.1 Sample Weather File

The SERI-RES program requires that the weather be formatted with the following fields:

A	Direct normal solar irradiance in tenths of $kJ.m^{-2}.h^{-1}$ (5 characters)
B	Global (i.e. total horizontal) solar irradiance in tenths of $kJ.m^{-2}.h^{-1}$ (5 characters)
C	Ambient dry bulb temperature in tenths of a degree C (4 characters)
D	Ambient dew point temperature in tenths of a degree C (4 characters)
E	Wind speed in tenths of $m.s^{-1}$ (4 characters)

The following list shows the typical January 24 hour weather profile for Gilgit as an example of the data presented in this format:

```
 0   0  3 -39  3
 0   0 -9 -39  3
 0   0 -19 -39  3
 0   0 -25 -38  3
 0   0 -27 -38  3
 0   0 -25 -39  5
 0   0 -19 -39  3
 0   0 -9 -40  3
17955 4563  3 -41  4
2600411545  17 -41  5
2814116904  33 -42  5
2895720274  49 -43  5
2918121423  63 -43  4
2895720274  75 -44  4
2814116904  85 -44  4
2600411545  91 -43  3
17955 4563  93 -43  3
 0   0 91 -42  3
 0   0 85 -42  3
 0   0 75 -42  3
 0   0 63 -41  3
 0   0 49 -41  3
 0   0 33 -40  3
 0   0 17 -40  3
```

12.2 Ghakuch baseline condition winter input file, revised 2/18/96

```
RUNS
*     RUN LABEL     STATION    GROUND GROUND -START- -STOP-- SKYLINE  PAR.
*                    NAME       REFL.  TEMP. MON DAY MON DAY PROFILE  TYPE
*                              [FRAC]   [C]  [DATE]  [DATE]
*AAAAAAAAAAAAAAAA AAAAAAAAAA S.SSSS SSS.SS AAA XX. AAA XX. AAAAAA  AAAAAA
 GHAKUCH          OCTOBER    0.2    GROUND OCT  1. OCT  25. SKY     <NONE>
 GHAKUCH          NOVEMBER   0.2    GROUND NOV  1. NOV  25. SKY     <NONE>
 GHAKUCH          DECEMBER   0.2    GROUND DEC  1. DEC  25. SKY     <NONE>
 GHAKUCH          JANUARY    0.2    GROUND JAN  1. JAN  25. SKY     <NONE>
 GHAKUCH          FEBRUARY   0.2    GROUND FEB  1. FEB  25. SKY     <NONE>
 GHAKUCH          MARCH      0.2    GROUND MAR  1. MAR  25. SKY     <NONE>
ZONES
*   ZONE       HVAC       FLOOR  HGT  INFIL.  SOLAR  SOLAR INTERNAL  LATENT
*   NAME       TYPE       AREA         RATE  TO AIR  LOST    GAIN     GAIN
*                         [SM]   [M]  [AC/H] [FRAC] [FRAC]   [KW]     [KW]
*AAAAAAAAAA AAAAAAAAAA XXXXX.X XX.X SSS.SSS X.XXX  X.XXX SSSS.SSS SSSS.SSS
 CLASSROOM1 WOODSTOVE     35.7  3.2   1.4   0.15   0.04  CR-SENS  CR-LAT
 CLASSROOM2 WOODSTOVE     35.7  3.2   1.4   0.15   0.04  CR-SENS  CR-LAT
 OFFICE     WOODSTOVE     23.8  3.2   1.4   0.15   0.035 OF-SENS  OF-LAT
 CLASSROOM4 WOODSTOVE     23.8  3.2   1.4   0.15   0.035 CR-SENS  CR-LAT
 CORRIDOR   <NONE>        25.3  3.2   1.4   0.15   0.057    0.000    0.000
WINDOWS
* INTERIOR   EXTERIOR   GLAZING   HEIGHT LENGTH --LOCATION--  EXTERIOR
*   ZONE     SURFACE     TYPE                   HORZ.  VERT.   ZONE
*                                  [M]    [M]    [M]    [M]
*AAAAAAAAAA AAAAAAAAAA AAAAAAAAAA XXX.XX XXX.XX XXXX.XX XXXX.XX AAAAAAAAAA
 CLASSROOM1 NORTHWEST  DOUBLE       1.52   1.22    1.02    0.61 AMBIENT
 CLASSROOM1 NORTHWEST  DOUBLE       1.52   1.22    3.45    0.61 AMBIENT
 CLASSROOM1 NORTHWEST  DOUBLE       1.52   1.22    5.89    0.61 AMBIENT
 CLASSROOM1 NWSKY      FIBERGLS     0.61   2.44    2.44    4.27 AMBIENT
 CLASSROOM2 SOUTHEAST  DOUBLE       1.52   1.22    0.81    0.61 AMBIENT
 CLASSROOM2 SOUTHEAST  DOUBLE       1.52   1.22    3.25    0.61 AMBIENT
```

```
 CLASSROOM2 SOUTHEAST  DOUBLE        1.52    1.22      5.69      0.61 AMBIENT
 CLASSROOM2 SESKY      FIBERGLS      0.61    2.44      2.44      0.   AMBIENT
 OFFICE     SOUTHWEST  DOUBLE        1.52    1.22      1.02      0.61 AMBIENT
 OFFICE     SOUTHWEST  DOUBLE        1.52    1.22      3.45      0.61 AMBIENT
 OFFICE     SESKY      FIBERGLS      0.61    2.44      0.        0.   AMBIENT
 CLASSROOM4 SOUTHWEST  DOUBLE        1.52    1.22      1.02      0.61 AMBIENT
 CLASSROOM4 SOUTHWEST  DOUBLE        1.52    1.22      3.45      0.61 AMBIENT
 CLASSROOM4 NWSKY      FIBERGLS      0.61    2.44      0.        4.27 AMBIENT
 CORRIDOR   NORTHWEST  SINGLE        1.64    1.64      0.        0.   AMBIENT
 CORRIDOR   SOUTHEAST  SINGLE        1.64    1.64      0.        0.   AMBIENT
 CORRIDOR   SESKY      FIBERGLS      0.61    2.44      0.        3.97 AMBIENT
 CORRIDOR   NWSKY      FIBERGLS      0.61    2.44      0.        4.58 AMBIENT
WALLS
*   WALL      --FRONT/INTERIOR SIDE--  --BACK/EXTERIOR SIDE---    WALL
*   TYPE        ZONE     SURF   SOLAR  ZONE OR     SURF  SOLAR    AREA
*               NAME     COEF   COEF.  SURFACE,    COEF  COEF.
*                        [W/C  [FRAC]  AMBIENT,    [W/C  [FRAC]   [SM]
*                        -SM]          GROUND      -SM]
*AAAAAAAAAA AAAAAAAAAA XX.XXX X.XXXX AAAAAAAAAA XX.XXX X.XXXX  XXXXX.X
 ROOF       CORRIDOR    8.278 <AREA> NWSKY      22.7   <AREA>     12.7
 ROOF       CORRIDOR    8.278 <AREA> SESKY      22.7   <AREA>     12.7
 ROOF       CLASSROOM1  8.278 <AREA> NWSKY      22.7   <AREA>     35.7
 ROOF       CLASSROOM2  8.278 <AREA> SESKY      22.7   <AREA>     35.7
 ROOF       OFFICE      8.278 <AREA> SESKY      22.7   <AREA>     23.8
 ROOF       CLASSROOM4  8.278 <AREA> NWSKY      22.7   <AREA>     23.8
 EXT_NORTH  CLASSROOM1  8.278 <AREA> NORTHWEST  18.2   <AREA>     19.8
 EXT_NORTH  CLASSROOM1  8.278 <AREA> NORTHEAST  18.2   <AREA>     13.2
 CORRI/OCC  CLASSROOM1  8.278 <AREA> CORRIDOR    8.278 <AREA>     11.2
 DOOR       CLASSROOM1  8.278 <AREA> CORRIDOR    8.278 <AREA>      2.2
 SHRD_OCCUP CLASSROOM1  8.278 <AREA> CLASSROOM2  8.278 <AREA>     19.8
 EXT_NORTH  CLASSROOM2  8.278 <AREA> NORTHEAST  18.2   <AREA>     13.2
 EXT_SE     CLASSROOM2  8.278 <AREA> SOUTHEAST  18.2   <AREA>     19.8
 CORRI/OCC  CLASSROOM2  8.278 <AREA> CORRIDOR    8.278 <AREA>     11.2
```

```
 DOOR        CLASSROOM2  8.278 <AREA> CORRIDOR    8.278 <AREA>     2.2
 EXT_SE      OFFICE      8.278 <AREA> SOUTHEAST  18.2   <AREA>    13.2
 EXT_SW      OFFICE      8.278 <AREA> SOUTHWEST  18.2   <AREA>    13.2
 CORRI/OCC   OFFICE      8.278 <AREA> CORRIDOR    8.278 <AREA>    11.2
 DOOR        OFFICE      8.278 <AREA> CORRIDOR    8.278 <AREA>     2.2
 SHRD_OCCUP  CLASSROOM4  8.278 <AREA> OFFICE      8.278 <AREA>    13.2
 EXT_SW      CLASSROOM4  8.278 <AREA> SOUTHWEST  18.2   <AREA>    13.2
 EXT_NORTH   CLASSROOM4  8.278 <AREA> NORTHWEST  18.2   <AREA>    13.2
 CORRI/OCC   CLASSROOM4  8.278 <AREA> CORRIDOR    8.278 <AREA>    11.2
 DOOR        CLASSROOM4  8.278 <AREA> CORRIDOR    8.278 <AREA>     2.2
 DOOR        CORRIDOR    8.278 <AREA> NORTHWEST  18.2   <AREA>     6.7
 DOOR        CORRIDOR    8.278 <AREA> SOUTHEAST  18.2   <AREA>     6.7
 GFLOOR      CORRIDOR    8.278 <AREA> GROUND     99.99  <AREA>    25.3
 GFLOOR      CLASSROOM1  8.278 <AREA> GROUND     99.99  <AREA>    35.7
 GFLOOR      CLASSROOM2  8.278 <AREA> GROUND     99.99  <AREA>    35.7
 GFLOOR      OFFICE      8.278 <AREA> GROUND     99.99  <AREA>    23.8
 GFLOOR      CLASSROOM4  8.278 <AREA> GROUND     99.99  <AREA>    23.8
SURFACES
*  SURFACE    COMPASS   TILT  HEIGHT  LENGTH  ---------  SHADING  ---------
*             AZIMUTH                          PARALLEL   LEFT       RIGHT
*                                                TYPE     PERPEND    PERPEND
*              [DEG]  [DEG]   [M]      [M]
*AAAAAAAAAA   XXX.X    XX.X XXXX.XX XXXX.XX AAAAAAAAAA AAAAAAAAAA AAAAAAAAAA
 NORTHEAST     65.     90.      3.2     10.9 <NONE>     <NONE>     <NONE>
 SOUTHEAST    155.     90.      3.2     16.2 <NONE>     <NONE>     <NONE>
 SOUTHWEST    245.     90.      3.2     10.9 <NONE>     <NONE>     <NONE>
 NORTHWEST    335.     90.      3.2     16.2 <NONE>     <NONE>     <NONE>
 NWSKY        335.     28.8     6.22    16.2 <NONE>     <NONE>     <NONE>
 SESKY        155.     28.8     6.22    16.2 <NONE>     <NONE>     <NONE>
HVAC.TYPES
*    HVAC     HEATING  VENTING  COOLING  HEATING  VENTING  COOLING   COOLER
*    TYPE     SETPOINT SETPOINT SETPOINT CAPACITY CAPACITY CAPACITY   COIL
*               [C]      [C]      [C]      [KW]    [AC/H]    [KW]      [C]
```

```
*AAAAAAAAAA SSS.SSS  SSS.SSS  SSS.SSS  XXXX.XXX  XXX.XX  XXXX.XXX     XX.X
 WOODSTOVE  HEATING  <NONE>   <NONE>   <ADEQ>      0.0      0.0       12.8
WALL.TYPES
*   WALL      LAYER     LAYER     LAYER     LAYER     LAYER     LAYER
*   TYPE       # 1       # 2       # 3       # 4       # 5       # 6
*AAAAAAAAAA AAAAAAAAA AAAAAAAAA AAAAAAAAA AAAAAAAAA AAAAAAAAA AAAAAAAAA
 DOOR       WOOD      <NONE>    <NONE>    <NONE>    <NONE>    <NONE>
 CORRI/OCC  GRANITE   <NONE>    <NONE>    <NONE>    <NONE>    <NONE>
 EXT_NORTH  GRANITE   <NONE>    <NONE>    <NONE>    <NONE>    <NONE>
 EXT_SE     GRANITE   <NONE>    <NONE>    <NONE>    <NONE>    <NONE>
 EXT_SW     GRANITE   <NONE>    <NONE>    <NONE>    <NONE>    <NONE>
 SHRD_OCCUP GRANITE   <NONE>    <NONE>    <NONE>    <NONE>    <NONE>
 GFLOOR     CONC75    STONE1    R-2.022   <NONE>    <NONE>    <NONE>
 ROOF       ROOF      <NONE>    <NONE>    <NONE>    <NONE>    <NONE>
MASS.TYPES
*MASS TYPE   CONDUCTIVITY   DENSITY   SPECIFIC HEAT  THICKNESS  NODES
*               [W/M-C]     [KG/CM]     [KJ/KG-C]       [M]
*AAAAAAAAAA      X.XXXX     XXXX.XXX     X.XXXX       XX.XXXX    XX.
 CONC75          1.4        2100.        0.653         0.0762     1.
 GRANITE         1.787      2466.        0.8374        0.381      1.
 INSUL_R5        0.0288       98.        1.339         0.0254     1.
 INSUL_R10       0.0288       98.        1.339         0.0508     1.
 GYPSMSAND       0.7999     1682.        0.8368        0.0127     1.
 POLYST_R5       0.0288       60.        1.210         0.0254     1.
 WOOD_LATH       0.115       513.        1.0           0.0064     1.
 ROOF            0.055       550.        1.0           0.127      1.
 SOIL            1.6        1785.        1.84          0.15       1.
 STONE1          1.73       2242.        0.837         0.127      1.
 WOOD            0.115       513.        2.64          0.0127     1.
GLAZING.TYPES
* GLAZING    GLAZING    SHADING EXTINCTION  INDEX OF  THICKNESS  NUMBER
*  TYPE      U VALUE     COEF.     COEF.   REFRACTION OF LAYER     OF
*           [W/SM-C]    [FRAC]    [1/MM]     [NONE]     [MM]     LAYERS
```

```
*AAAAAAAAAA  SS.SSSSS  SS.SSSSS  X.XXXX     X.XXXX    X.XXXX       XX.
 DOUBLE       2.78      0.66     0.0197     1.5260    3.1750        2.
 SINGLE       5.67      0.81     0.0197     1.5260    3.1750        1.
 FIBERGLS     5.67      0.592    0.0197     1.5260    3.1750        1.
SKYLINE.TYPES
*SKYLINE  --------- ALTITUDE ANGLE OF SKYLINE [DEGREES] -------*PROFILE  ---EAST----------
--------SOUTH-----------------WEST---
* NAME    100   80   60   40   20    0   20   40   60   80   100
*AAAAAA   XX.X XX.X XX.X XX.X XX.X XX.X XX.X XX.X XX.X XX.X XX.X
 SKY      27.  21.  13.  30.  29.  35.  35.  52.  25.  65.  16.
OUTPUTS
* OUTPUT   TIME    UNITS   OUTPUT   BUILDING   OUTPUT   FORMAT?
*  TYPE   PERIOD           SEASON   ELEMENT    SECTION
*         [H/D/M] [E/M]                                  [Y/N]
*AAAAAAAA   A       A    AAAAAAAA    XXXX.     XXXX.       A
 AMBIENT    M       M    <ALL>       <ALL>     <ALL>       Y
 BUILDING   D       M    <ALL>       <ALL>     <ALL>       Y
 ZONES      M       M    <ALL>       <ALL>     <ALL>       Y
SCHEDULES
*SCHEDULE  SEASON  HR   VALUE    HR   VALUE    HR   VALUE    HR   VALUE
*AAAAAAAA AAAAAAAA XX. XXXX.XXX  XX. XXXX.XXX  XX. XXXX.XXX  XX. XXXX.XXX
 HEATING  WINTER    7.  17.      15.    0.
 CR-SENS  WINTER    7.    1.47   15.    0.
 CR-LAT   WINTER    7.    1.197  15.    0.
 OF-SENS  WINTER    7.    0.070  15.    0.
 OF-LAT   WINTER    7.    0.055  15.    0.
 GROUND   OCT       1.  27.4     24.   27.4
 GROUND   NOV       1.  26.7     24.   26.7
 GROUND   DEC       1.  22.1     24.   22.1
 GROUND   JAN       1.  15.9     24.   15.9
 GROUND   FEB       1.   9.2     24.    9.2
 GROUND   MAR       1.   4.3     24.    4.3
SEASONS
```

```
* SEASON      START DATE    STOP DATE    DAY OF WEEK
*  NAME         MON DAY      MON DAY    [ALL/M-F/S-S]
*AAAAAAAA       AAA XX.      AAA XX.         AAA
 WINTER         OCT  1.      MAR 31.         ALL
 OCT            OCT  1.      OCT 31.         ALL
 NOV            NOV  1.      NOV 30.         ALL
 DEC            DEC  1.      DEC 31.         ALL
 JAN            JAN  1.      JAN 31.         ALL
 FEB            FEB  1.      FEB 28.         ALL
 MAR            MAR  1.      MAR 31.         ALL
STATIONS
* STATION     LAT.  LONG.  ELEV.  FILENAME    DATA   UNITS   -START-   -STOP--
*  NAME      [DEG] [DEG]  [M]                 TYPE   [E/M]   MON DAY   MON DAY
*AAAAAAAAAA XX.XX XXX.X XXXXX. AAAAAAAAAA     XX.      A     AAA XX.   AAA XX.
 OCTOBER    35.91  74.3  1469. OCTOBER.R       3.      M     OCT  1.   OCT   30.
 NOVEMBER   35.91  74.3  1469. NOVEMBER.R      3.      M     NOV  1.   NOV   30.
 DECEMBER   35.91  74.3  1469. DECEMBER.R      3.      M     DEC  1.   DEC   30.
 JANUARY    35.91  74.3  1469. JANUARY.R       3.      M     JAN  1.   JAN   30.
 FEBRUARY   35.91  74.3  1469. FEBRUARY.R      3.      M     FEB  1.   FEB   28.
 MARCH      35.91  74.3  1469. MARCH.R         3.      M     MAR  1.   MAR   30.
END OF FILE
```

12.2.1 Alternative Ghakuch Simulation Scenarios

The following is a list of 12 alternative scenarios that were run for the Ghakuch School. These scenarios differ only in thermal insulation quantity and the choice of placement on the walls and ceiling. Therefore only the Wall Types section of each alternative input file has been included. The first set of six scenarios utilize R10 insulation and the second set of six use R5 thermal insulation.

```
Scenario 1, R10 insulation applied
R-10 on Ext Walls, winter input for Ghakuch School, rev. 2/18/96
WALL.TYPES
```

```
*   WALL       LAYER      LAYER      LAYER      LAYER      LAYER      LAYER
*   TYPE        # 1        # 2        # 3        # 4        # 5        # 6
*AAAAAAAAAA AAAAAAAAA  AAAAAAAAA  AAAAAAAAA  AAAAAAAAA  AAAAAAAAA  AAAAAAAAA
 DOOR        WOOD       <NONE>     <NONE>     <NONE>     <NONE>     <NONE>
 CORRI/OCC   GRANITE    <NONE>     <NONE>     <NONE>     <NONE>     <NONE>
 EXT_NORTH   GYPSMSAND  WOOD_LATH  INSUL_R10  GRANITE    <NONE>     <NONE>
 EXT_SE      GYPSMSAND  WOOD_LATH  INSUL_R10  GRANITE    <NONE>     <NONE>
 EXT_SW      GYPSMSAND  WOOD_LATH  INSUL_R10  GRANITE    <NONE>     <NONE>
 SHRD_OCCUP  GRANITE    <NONE>     <NONE>     <NONE>     <NONE>     <NONE>
 GFLOOR      CONC75     STONE1     R-2.022    <NONE>     <NONE>     <NONE>
 ROOF        ROOF       <NONE>     <NONE>     <NONE>     <NONE>     <NONE>

Scenario 2, R10 insulation applied
R-10 on Ext Walls Except SE, Ghakuch School, rev. 2/18/96
WALL.TYPES
*   WALL       LAYER      LAYER      LAYER      LAYER      LAYER      LAYER
*   TYPE        # 1        # 2        # 3        # 4        # 5        # 6
*AAAAAAAAAA AAAAAAAAA  AAAAAAAAA  AAAAAAAAA  AAAAAAAAA  AAAAAAAAA  AAAAAAAAA
 DOOR        WOOD       <NONE>     <NONE>     <NONE>     <NONE>     <NONE>
 CORRI/OCC   GRANITE    <NONE>     <NONE>     <NONE>     <NONE>     <NONE>
 EXT_NORTH   GYPSMSAND  WOOD_LATH  INSUL_R10  GRANITE    <NONE>     <NONE>
 EXT_SE      GRANITE    <NONE>     <NONE>     <NONE>     <NONE>     <NONE>
 EXT_SW      GYPSMSAND  WOOD_LATH  INSUL_R10  GRANITE    <NONE>     <NONE>
 SHRD_OCCUP  GRANITE    <NONE>     <NONE>     <NONE>     <NONE>     <NONE>
 GFLOOR      CONC75     STONE1     R-2.022    <NONE>     <NONE>     <NONE>
 ROOF        ROOF       <NONE>     <NONE>     <NONE>     <NONE>     <NONE>

Scenario 3, R10 insulation applied
R-10 on Ext Walls and Ceiling, Ghakuch School, rev. 2/18/96
WALL.TYPES
*   WALL       LAYER      LAYER      LAYER      LAYER      LAYER      LAYER
*   TYPE        # 1        # 2        # 3        # 4        # 5        # 6
*AAAAAAAAAA AAAAAAAAA  AAAAAAAAA  AAAAAAAAA  AAAAAAAAA  AAAAAAAAA  AAAAAAAAA
 DOOR        WOOD       <NONE>     <NONE>     <NONE>     <NONE>     <NONE>
```

```
 CORRI/OCC   GRANITE   <NONE>    <NONE>    <NONE>    <NONE>    <NONE>
 EXT_NORTH   GYPSMSAND WOOD_LATH INSUL_R10 GRANITE   <NONE>    <NONE>
 EXT_SE      GYPSMSAND WOOD_LATH INSUL_R10 GRANITE   <NONE>    <NONE>
 EXT_SW      GYPSMSAND WOOD_LATH INSUL_R10 GRANITE   <NONE>    <NONE>
 SHRD_OCCUP  GRANITE   <NONE>    <NONE>    <NONE>    <NONE>    <NONE>
 GFLOOR      CONC75    STONE1    R-2.022   <NONE>    <NONE>    <NONE>
 ROOF_CORR   ROOF      <NONE>    <NONE>    <NONE>    <NONE>    <NONE>
 ROOF_OCC    GYPSMSAND WOOD_LATH INSUL_R10 ROOF      <NONE>    <NONE>

Scenario 4, R10 insulation applied
R-10 on Ext & Occ/Corridr walls, Ghakuch School, rev. 2/18/96     WALL.TYPES
*   WALL       LAYER     LAYER     LAYER     LAYER     LAYER     LAYER
*   TYPE        # 1       # 2       # 3       # 4       # 5       # 6
*AAAAAAAAAA AAAAAAAAA AAAAAAAAA AAAAAAAAA AAAAAAAAA AAAAAAAAA AAAAAAAAA
 DOOR        WOOD      <NONE>    <NONE>    <NONE>    <NONE>    <NONE>
 CORRI/OCC   GYPSMSAND WOOD_LATH INSUL_R10 GRANITE   <NONE>    <NONE>
 EXT_NORTH   GYPSMSAND WOOD_LATH INSUL_R10 GRANITE   <NONE>    <NONE>
 EXT_SE      GYPSMSAND WOOD_LATH INSUL_R10 GRANITE   <NONE>    <NONE>
 EXT_SW      GYPSMSAND WOOD_LATH INSUL_R10 GRANITE   <NONE>    <NONE>
 SHRD_OCCUP  GRANITE   <NONE>    <NONE>    <NONE>    <NONE>    <NONE>
 GFLOOR      CONC75    STONE1    R-2.022   <NONE>    <NONE>    <NONE>
 ROOF        ROOF      <NONE>    <NONE>    <NONE>    <NONE>    <NONE>

Scenario 5, R10 insulation applied
R-10 on Ext and Shared Walls, Ghakuch School, rev. 2/18/96
WALL.TYPES
*   WALL       LAYER     LAYER     LAYER     LAYER     LAYER     LAYER
*   TYPE        # 1       # 2       # 3       # 4       # 5       # 6
*AAAAAAAAAA AAAAAAAAA AAAAAAAAA AAAAAAAAA AAAAAAAAA AAAAAAAAA AAAAAAAAA
 DOOR        WOOD      <NONE>    <NONE>    <NONE>    <NONE>    <NONE>
 CORRI/OCC   GYPSMSAND WOOD_LATH INSUL_R10 GRANITE   <NONE>    <NONE>
 EXT_NORTH   GYPSMSAND WOOD_LATH INSUL_R10 GRANITE   <NONE>    <NONE>
 EXT_SE      GYPSMSAND WOOD_LATH INSUL_R10 GRANITE   <NONE>    <NONE>
 EXT_SW      GYPSMSAND WOOD_LATH INSUL_R10 GRANITE   <NONE>    <NONE>
```

```
 SHRD_OCCUP GYPSMSAND WOOD_LATH INSUL_R5  GRANITE   INSUL_R5  GYPSMSAND
 GFLOOR     CONC75    STONE1    R-2.022   <NONE>    <NONE>    <NONE>
 ROOF       ROOF      <NONE>    <NONE>    <NONE>    <NONE>    <NONE>
```

```
Scenario 6, R10 insulation applied
R-10 on Ext,Shared Walls,and Ceiling Ghakuch School, rev. 2/18/96  WALL.TYPES
*   WALL       LAYER      LAYER     LAYER      LAYER      LAYER      LAYER
*   TYPE        # 1        # 2       # 3        # 4        # 5        # 6
*AAAAAAAAAA AAAAAAAAA AAAAAAAAA AAAAAAAAA AAAAAAAAA AAAAAAAAA AAAAAAAAA
 DOOR       WOOD      <NONE>    <NONE>    <NONE>    <NONE>    <NONE>
 CORRI/OCC  GYPSMSAND WOOD_LATH INSUL_R10 GRANITE   <NONE>    <NONE>
 EXT_NORTH  GYPSMSAND WOOD_LATH INSUL_R10 GRANITE   <NONE>    <NONE>
 EXT_SE     GYPSMSAND WOOD_LATH INSUL_R10 GRANITE   <NONE>    <NONE>
 EXT_SW     GYPSMSAND WOOD_LATH INSUL_R10 GRANITE   <NONE>    <NONE>
 SHRD_OCCUP GYPSMSAND WOOD_LATH INSUL_R5  GRANITE   INSUL_R5  GYPSMSAND
 GFLOOR     CONC75    STONE1    R-2.022   <NONE>    <NONE>    <NONE>
 ROOF_CORR  ROOF      <NONE>    <NONE>    <NONE>    <NONE>    <NONE>
 ROOF_OCC   GYPSMSAND WOOD_LATH INSUL_R10 ROOF      <NONE>    <NONE>
```

```
Scenario 1, R5 insulation applied
R-5 on Ext Walls, winter input for Ghakuch School, rev. 2/18/96 WALL.TYPES
*   WALL       LAYER      LAYER     LAYER      LAYER      LAYER      LAYER
*   TYPE        # 1        # 2       # 3        # 4        # 5        # 6
*AAAAAAAAAA AAAAAAAAA AAAAAAAAA AAAAAAAAA AAAAAAAAA AAAAAAAAA AAAAAAAAA
 DOOR       WOOD      <NONE>    <NONE>    <NONE>    <NONE>    <NONE>
 CORRI/OCC  GRANITE   <NONE>    <NONE>    <NONE>    <NONE>    <NONE>
 EXT_NORTH  GYPSMSAND WOOD_LATH INSUL_R5  GRANITE   <NONE>    <NONE>
 EXT_SE     GYPSMSAND WOOD_LATH INSUL_R5  GRANITE   <NONE>    <NONE>
 EXT_SW     GYPSMSAND WOOD_LATH INSUL_R5  GRANITE   <NONE>    <NONE>
 SHRD_OCCUP GRANITE   <NONE>    <NONE>    <NONE>    <NONE>    <NONE>
 GFLOOR     CONC75    STONE1    R-2.022   <NONE>    <NONE>    <NONE>
 ROOF       ROOF      <NONE>    <NONE>    <NONE>    <NONE>    <NONE>
```

```
Scenario 2, R5 insulation applied
R-5 on Ext Walls Except SE, Ghakuch School, rev. 2/18/96
WALL.TYPES
*   WALL       LAYER     LAYER     LAYER     LAYER     LAYER     LAYER
*   TYPE        # 1       # 2       # 3       # 4       # 5       # 6
*AAAAAAAAAA AAAAAAAAA AAAAAAAAA AAAAAAAAA AAAAAAAAA AAAAAAAAA AAAAAAAAA
 DOOR       WOOD      <NONE>    <NONE>    <NONE>    <NONE>    <NONE>
 CORRI/OCC  GRANITE   <NONE>    <NONE>    <NONE>    <NONE>    <NONE>
 EXT_NORTH  GYPSMSAND WOOD_LATH INSUL_R5  GRANITE   <NONE>    <NONE>
 EXT_SE     GRANITE   <NONE>    <NONE>    <NONE>    <NONE>    <NONE>
 EXT_SW     GYPSMSAND WOOD_LATH INSUL_R5  GRANITE   <NONE>    <NONE>
 SHRD_OCCUP GRANITE   <NONE>    <NONE>    <NONE>    <NONE>    <NONE>
 GFLOOR     CONC75    STONE1    R-2.022   <NONE>    <NONE>    <NONE>
 ROOF       ROOF      <NONE>    <NONE>    <NONE>    <NONE>    <NONE>

Scenario 3, R5 insulation applied
R-5 on Occ. Ext Walls & Ceilings, Ghakuch School, rev. 2/18/96
WALL.TYPES
*   WALL       LAYER     LAYER     LAYER     LAYER     LAYER     LAYER
*   TYPE        # 1       # 2       # 3       # 4       # 5       # 6
*AAAAAAAAAA AAAAAAAAA AAAAAAAAA AAAAAAAAA AAAAAAAAA AAAAAAAAA AAAAAAAAA
 DOOR       WOOD      <NONE>    <NONE>    <NONE>    <NONE>    <NONE>
 CORRI/OCC  GRANITE   <NONE>    <NONE>    <NONE>    <NONE>    <NONE>
 EXT_NORTH  GYPSMSAND WOOD_LATH INSUL_R5  GRANITE   <NONE>    <NONE>
 EXT_SE     GYPSMSAND WOOD_LATH INSUL_R5  GRANITE   <NONE>    <NONE>
 EXT_SW     GYPSMSAND WOOD_LATH INSUL_R5  GRANITE   <NONE>    <NONE>
 SHRD_OCCUP GRANITE   <NONE>    <NONE>    <NONE>    <NONE>    <NONE>
 GFLOOR     CONC75    STONE1    R-2.022   <NONE>    <NONE>    <NONE>
 ROOF_CORR  ROOF      <NONE>    <NONE>    <NONE>    <NONE>    <NONE>
 ROOF_OCC   GYPSMSAND WOOD_LATH INSUL_R5  ROOF      <NONE>    <NONE>

Scenario 4, R5 insulation applied
R-5 on Ext & Occ/Corridr walls, Ghakuch School, rev. 2/18/96
WALL.TYPES
```

```
*   WALL       LAYER     LAYER     LAYER     LAYER     LAYER     LAYER
*   TYPE        # 1       # 2       # 3       # 4       # 5       # 6
*AAAAAAAAAA AAAAAAAAA AAAAAAAAA AAAAAAAAA AAAAAAAAA AAAAAAAAA AAAAAAAAA
 DOOR       WOOD      <NONE>    <NONE>    <NONE>    <NONE>    <NONE>
 CORRI/OCC  GYPSMSAND WOOD_LATH INSUL_R5  GRANITE   <NONE>    <NONE>
 EXT_NORTH  GYPSMSAND WOOD_LATH INSUL_R5  GRANITE   <NONE>    <NONE>
 EXT_SE     GYPSMSAND WOOD_LATH INSUL_R5  GRANITE   <NONE>    <NONE>
 EXT_SW     GYPSMSAND WOOD_LATH INSUL_R5  GRANITE   <NONE>    <NONE>
 SHRD_OCCUP GRANITE   <NONE>    <NONE>    <NONE>    <NONE>    <NONE>
 GFLOOR     CONC75    STONE1    R-2.022   <NONE>    <NONE>    <NONE>
 ROOF       ROOF      <NONE>    <NONE>    <NONE>    <NONE>    <NONE>

Scenario 5, R5 insulation applied
R-5 on Ext and Shared Walls, Ghakuch School, rev. 2/18/96
WALL.TYPES
*   WALL       LAYER     LAYER     LAYER     LAYER     LAYER     LAYER
*   TYPE        # 1       # 2       # 3       # 4       # 5       # 6
*AAAAAAAAAA AAAAAAAAA AAAAAAAAA AAAAAAAAA AAAAAAAAA AAAAAAAAA AAAAAAAAA
 DOOR       WOOD      <NONE>    <NONE>    <NONE>    <NONE>    <NONE>
 CORRI/OCC  GYPSMSAND WOOD_LATH INSUL_R5  GRANITE   <NONE>    <NONE>
 EXT_NORTH  GYPSMSAND WOOD_LATH INSUL_R5  GRANITE   <NONE>    <NONE>
 EXT_SE     GYPSMSAND WOOD_LATH INSUL_R5  GRANITE   <NONE>    <NONE>
 EXT_SW     GYPSMSAND WOOD_LATH INSUL_R5  GRANITE   <NONE>    <NONE>
 SHRD_OCCUP GYPSMSAND WOOD_LATH INSL_R2.5 GRANITE   INSL_R2.5 GYPSMSAND
 GFLOOR     CONC75    STONE1    R-2.022   <NONE>    <NONE>    <NONE>
 ROOF       ROOF      <NONE>    <NONE>    <NONE>    <NONE>    <NONE>

Scenario 6, R5 insulation applied
R-5 on Ext,Shared Walls,and Ceiling Ghakuch School, rev. 2/18/96 WALL.TYPES
*   WALL       LAYER     LAYER     LAYER     LAYER     LAYER     LAYER
*   TYPE        # 1       # 2       # 3       # 4       # 5       # 6
*AAAAAAAAAA AAAAAAAAA AAAAAAAAA AAAAAAAAA AAAAAAAAA AAAAAAAAA AAAAAAAAA
 DOOR       WOOD      <NONE>    <NONE>    <NONE>    <NONE>    <NONE>
 CORRI/OCC  GYPSMSAND WOOD_LATH INSUL_R5  GRANITE   <NONE>    <NONE>
```

```
EXT_NORTH   GYPSMSAND WOOD_LATH INSUL_R5   GRANITE    <NONE>     <NONE>
EXT_SE      GYPSMSAND WOOD_LATH INSUL_R5   GRANITE    <NONE>     <NONE>
EXT_SW      GYPSMSAND WOOD_LATH INSUL_R5   GRANITE    <NONE>     <NONE>
SHRD_OCCUP  GYPSMSAND WOOD_LATH INSL_R2.5  GRANITE    INSL_R2.5  GYPSMSAND
GFLOOR      CONC75    STONE1    R-2.022    <NONE>     <NONE>     <NONE>
ROOF_CORR   ROOF      <NONE>    <NONE>     <NONE>     <NONE>     <NONE>
ROOF_OCC    GYPSMSAND WOOD_LATH INSUL_R10  ROOF       <NONE>     <NONE>
```

12.3 Ahmedabad baseline condition winter input, revised 9/28/96


```
RUNS
*     RUN LABEL      STATION    GROUND GROUND -START- -STOP-- SKYLINE  PAR.
*                     NAME       REFL.  TEMP. MON DAY MON DAY PROFILE  TYPE
*                               [FRAC]   [C]  [DATE]  [DATE]
*AAAAAAAAAAAAAAAA AAAAAAAAAA S.SSSS SSS.SS AAA XX. AAA XX. AAAAAA  AAAAAA
 AHMEDABAD1       OCTOBER    0.2    GROUND OCT  1. OCT 25. SKY     <NONE>
 AHMEDABAD1       NOVEMBER   0.2    GROUND NOV  1. NOV 25. SKY     <NONE>
 AHMEDABAD1       DECEMBER   0.2    GROUND DEC  1. DEC 25. SKY     <NONE>
 AHMEDABAD1       JANUARY    0.2    GROUND JAN  1. JAN 25. SKY     <NONE>
 AHMEDABAD1       FEBRUARY   0.2    GROUND FEB  1. FEB 25. SKY     <NONE>
 AHMEDABAD1       MARCH      0.2    GROUND MAR  1. MAR 25. SKY     <NONE>
ZONES
*   ZONE       HVAC      FLOOR  HGT  INFIL.  SOLAR  SOLAR INTERNAL  LATENT
*   NAME       TYPE      AREA        RATE   TO AIR  LOST    GAIN     GAIN
*                        [SM]   [M]  [AC/H] [FRAC] [FRAC]   [KW]     [KW]
*AAAAAAAAAA AAAAAAAAAA XXXXX.X XX.X SSS.SSS X.XXX  X.XXX SSSS.SSS SSSS.SSS
 CLASSROOM1 WOODSTOVE     35.7  2.8   1.85  0.15   0.04  CR-INT   CR-LAT
 CLASSROOM2 WOODSTOVE     35.7  2.8   1.85  0.15   0.04  CR-INT   CR-LAT
 CLASSROOM3 WOODSTOVE     35.7  2.8   1.85  0.15   0.04  CR-INT   CR-LAT
 OFFICE     WOODSTOVE     11.9  2.8   1.85  0.15   0.03  OFF-INT  OFF-LAT
 CORRIDOR   <NONE>        23.8  3.4   1.85  0.15   0.05     0.       0.
```

```
WINDOWS
* INTERIOR    EXTERIOR    GLAZING    HEIGHT LENGTH --LOCATION--  EXTERIOR
*   ZONE      SURFACE      TYPE                     HORZ.  VERT.    ZONE
*                                      [M]     [M]   [M]    [M]
*AAAAAAAAAA AAAAAAAAAA AAAAAAAAAA XXX.XX XXX.XX XXXX.XX XXXX.XX AAAAAAAAAA
 CLASSROOM1 NORTHWEST  DOUBLE       1.27   1.02    0.81    0.61 AMBIENT
 CLASSROOM1 NORTHWEST  DOUBLE       1.27   1.02    3.25    0.61 AMBIENT
 CLASSROOM1 NORTHWEST  DOUBLE       1.27   1.02    5.69    0.61 AMBIENT
 CLASSROOM1 OPENSKY    FIBERGLAS    2.2    0.2     0.86    1.15 AMBIENT
 CLASSROOM1 OPENSKY    FIBERGLAS    0.61   2.2     4.16    4.02 AMBIENT
 CLASSROOM2 SOUTHEAST  DOUBLE       1.27   1.02    1.02    0.61 AMBIENT
 CLASSROOM2 SOUTHEAST  DOUBLE       1.27   1.02    3.45    0.61 AMBIENT
 CLASSROOM2 SOUTHEAST  DOUBLE       1.27   1.02    5.89    0.61 AMBIENT
 CLASSROOM2 OPENSKY    FIBERGLAS    0.61   2.2     4.16    0.29 AMBIENT
 CLASSROOM2 OPENSKY    FIBERGLAS    2.2    0.2     0.72    1.29 AMBIENT
 CLASSROOM3 NORTHEAST  DOUBLE       1.27   1.02    0.81    0.61 AMBIENT
 CLASSROOM3 NORTHEAST  DOUBLE       1.27   1.02    3.25    0.61 AMBIENT
 CLASSROOM3 NORTHEAST  DOUBLE       1.27   1.02    5.69    0.61 AMBIENT
 CLASSROOM3 OPENSKY    FIBERGLAS    2.2    0.61    3.73    0.57 AMBIENT
 CLASSROOM3 OPENSKY    FIBERGLAS    0.2    2.2     1.29    6.17 AMBIENT
 OFFICE     NORTHEAST  DOUBLE       1.27   1.02    1.02    0.61 AMBIENT
 CORRIDOR   NORTHWEST  SINGLE       2.26   2.26    0.      0.   AMBIENT
 CORRIDOR   SOUTHEAST  SINGLE       2.26   2.26    0.      0.   AMBIENT
WALLS
*   WALL     --FRONT/INTERIOR SIDE--  --BACK/EXTERIOR SIDE---   WALL
*   TYPE       ZONE     SURF   SOLAR  ZONE OR    SURF  SOLAR    AREA
*              NAME     COEF   COEF.  SURFACE,   COEF  COEF.
*                       [W/C  [FRAC]  AMBIENT,   [W/C  [FRAC]   [SM]
*                       -SM]          GROUND     -SM]
*AAAAAAAAAA AAAAAAAAAA XX.XXX X.XXXX AAAAAAAAAA XX.XXX X.XXXX  XXXXX.X
 GFLOOR     CORRIDOR    8.278 <AREA> GROUND      99.9  <AREA>     23.8
 GFLOOR     CLASSROOM1  8.278 <AREA> GROUND      99.9  <AREA>     35.7
 GFLOOR     CLASSROOM2  8.278 <AREA> GROUND      99.9  <AREA>     35.7
```

```
 GFLOOR     CLASSROOM3  8.278 <AREA> GROUND      99.9   <AREA>     35.7
 GFLOOR     OFFICE      8.278 <AREA> GROUND      99.9   <AREA>     11.9
 CCEILING   CORRIDOR    8.278 <AREA> OPENSKY     22.7   <AREA>     23.8
 CEILING    CLASSROOM1  8.278 <AREA> OPENSKY     22.7   <AREA>     35.7
 CEILING    CLASSROOM2  8.278 <AREA> OPENSKY     22.7   <AREA>     35.7
 CEILING    CLASSROOM3  8.278 <AREA> OPENSKY     22.7   <AREA>     35.7
 CEILING    OFFICE      8.278 <AREA> OPENSKY     22.7   <AREA>     11.9
 EXT_NW     CLASSROOM1  8.278 <AREA> NORTHWEST   18.2   <AREA>     20.4
 CORRI/OCC  CLASSROOM1  8.278 <AREA> CORRIDOR     8.278 <AREA>     11.6
 SHRD_OCCUP CLASSROOM1  8.278 <AREA> CLASSROOM2   8.278 <AREA>     20.4
 EXT_SW     CLASSROOM1  8.278 <AREA> SOUTHWEST   18.2   <AREA>     13.6
 DOOR       CLASSROOM1  8.278 <AREA> CORRIDOR     8.278 <AREA>      2.
 CORRI/OCC  CLASSROOM2  8.278 <AREA> CORRIDOR     8.278 <AREA>     11.6
 EXT_SE     CLASSROOM2  8.278 <AREA> SOUTHEAST   18.2   <AREA>     20.4
 EXT_SW     CLASSROOM2  8.278 <AREA> SOUTHWEST   18.2   <AREA>     13.6
 DOOR       CLASSROOM2  8.278 <AREA> CORRIDOR     8.278 <AREA>      2.
 SHRD_OCCUP CLASSROOM3  8.278 <AREA> OFFICE       8.278 <AREA>     13.6
 EXT_NE     CLASSROOM3  8.278 <AREA> NORTHEAST   18.2   <AREA>     20.4
 EXT_SE     CLASSROOM3  8.278 <AREA> SOUTHEAST   18.2   <AREA>     13.6
 CORRI/OCC  CLASSROOM3  8.278 <AREA> CORRIDOR     8.278 <AREA>     18.4
 DOOR       CLASSROOM3  8.278 <AREA> CORRIDOR     8.278 <AREA>      2.
 EXT_NW     OFFICE      8.278 <AREA> NORTHWEST   18.2   <AREA>     13.6
 EXT_NE     OFFICE      8.278 <AREA> NORTHEAST   18.2   <AREA>      6.8
 CORRI/OCC  OFFICE      8.278 <AREA> CORRIDOR     8.278 <AREA>      4.8
 DOOR       OFFICE      8.278 <AREA> CORRIDOR     8.278 <AREA>      2.
 DOOR       CORRIDOR    8.278 <AREA> NORTHWEST   18.2   <AREA>      8.2
 DOOR       CORRIDOR    8.278 <AREA> SOUTHEAST   18.2   <AREA>      8.2
SURFACES
* SURFACE   COMPASS  TILT  HEIGHT  LENGTH  ---------  SHADING  ---------
*           AZIMUTH                        PARALLEL    LEFT       RIGHT
*                                            TYPE     PERPEND    PERPEND
*            [DEG]  [DEG]   [M]      [M]
*AAAAAAAAAA  XXX.X   XX.X XXXX.XX XXXX.XX AAAAAAAAAA AAAAAAAAAA AAAAAAAAAA
```

```
 NORTHWEST   350.     90.      2.79   14.64 <NONE>     <NONE>     <NONE>
 NORTHEAST    80.     90.      2.79    9.76 <NONE>     <NONE>     <NONE>
 SOUTHEAST   170.     90.      2.79   14.64 <NONE>     <NONE>     <NONE>
 SOUTHWEST   260.     90.      2.79    9.76 <NONE>     <NONE>     <NONE>
 OPENSKY       0.      0.     14.64    9.76 <NONE>     <NONE>     <NONE>
HVAC.TYPES
*   HVAC    HEATING  VENTING  COOLING  HEATING  VENTING  COOLING   COOLER
*   TYPE    SETPOINT SETPOINT SETPOINT CAPACITY CAPACITY CAPACITY   COIL
*             [C]      [C]      [C]      [KW]    [AC/H]    [KW]     [C]
*AAAAAAAAAA SSS.SSS  SSS.SSS  SSS.SSS  XXXX.XXX XXX.XX  XXXX.XXX   XX.X
 WOODSTOVE  HEATING  <NONE>   <NONE>   <ADEQ>      0.        0.    12.8
WALL.TYPES
*   WALL     LAYER     LAYER     LAYER     LAYER     LAYER     LAYER
*   TYPE      # 1       # 2       # 3       # 4       # 5       # 6
*AAAAAAAAAA AAAAAAAAA AAAAAAAAA AAAAAAAAA AAAAAAAAA AAAAAAAAA AAAAAAAAA
 GFLOOR     CONC75    STONE1    R-2.022   <NONE>    <NONE>    <NONE>
 EXT_NW     HCCONCRET <NONE>    <NONE>    <NONE>    <NONE>    <NONE>
 EXT_NE     HCCONCRET <NONE>    <NONE>    <NONE>    <NONE>    <NONE>
 EXT_SW     HCCONCRET <NONE>    <NONE>    <NONE>    <NONE>    <NONE>
 EXT_SE     HCCONCRET <NONE>    <NONE>    <NONE>    <NONE>    <NONE>
 CORRI/OCC  HCCONCRET <NONE>    <NONE>    <NONE>    <NONE>    <NONE>
 SHRD_OCCUP HCCONCRET <NONE>    <NONE>    <NONE>    <NONE>    <NONE>
 CEILING    ROOFMEAS  <NONE>    <NONE>    <NONE>    <NONE>    <NONE>
 CCEILING   ROOFMEAS  <NONE>    <NONE>    <NONE>    <NONE>    <NONE>
 DOOR       WOOD      <NONE>    <NONE>    <NONE>    <NONE>    <NONE>
MASS.TYPES
*MASS TYPE   CONDUCTIVITY   DENSITY   SPECIFIC HEAT  THICKNESS  NODES
*              [W/M-C]      [KG/CM]     [KJ/KG-C]       [M]
*AAAAAAAAAA    X.XXXX      XXXX.XXX      X.XXXX       XX.XXXX    XX.
 CONC75        1.4         2100.         0.653         0.0762     1.
 HCCONCRET     0.6500      2272.         0.6533        0.203      1.
 INSUL_R5      0.0288        98.         1.339         0.0254     1.
 INSUL_R10     0.0288        98.         1.339         0.0508     1.
```

```
 GYPSMSAND      0.7999     1682.         0.8368        0.0127     1.
 ROOFMEAS       0.7247     2143.         0.8181        0.266      1.
 SOIL           1.6        1785.         1.84          0.15       1.
 STONE1         1.73       2242.         0.837         0.127      1.
 WOOD_LATH      0.115       513.         2.64          0.0064     1.
 WOOD           0.115       513.         2.64          0.0127     1.
GLAZING.TYPES
* GLAZING     GLAZING    SHADING EXTINCTION  INDEX OF  THICKNESS  NUMBER
*  TYPE       U VALUE     COEF.     COEF.   REFRACTION OF LAYER     OF
*             [W/SM-C]   [FRAC]    [1/MM]     [NONE]     [MM]     LAYERS
*AAAAAAAAAA   SS.SSSSS   SS.SSSSS  X.XXXX     X.XXXX    X.XXXX      XX.
 SINGLE        5.67       0.9      0.0197     1.5260    3.1750        1.
 DOUBLE        2.78       0.88     0.0197     1.5260    3.1750        2.
 FIBERGLAS     5.67       0.74     0.0197     1.5260    3.1750        1.
SKYLINE.TYPES
*SKYLINE  --------- ALTITUDE ANGLE OF SKYLINE [DEGREES] -------*PROFILE  ---EAST----------
--------SOUTH-----------------WEST---
* NAME    100   80   60   40   20    0   20   40   60   80   100
*AAAAAA   XX.X XX.X XX.X XX.X XX.X XX.X XX.X XX.X XX.X XX.X XX.X
 SKY      35.  38.  21.  26.  28.  23.  25.  18.  30.  31.  36.
OUTPUTS
* OUTPUT   TIME   UNITS   OUTPUT   BUILDING   OUTPUT   FORMAT?
*  TYPE   PERIOD          SEASON   ELEMENT    SECTION
*         [H/D/M] [E/M]                                  [Y/N]
*AAAAAAAA   A       A    AAAAAAAA    XXXX.     XXXX.       A
 AMBIENT    M       M    <ALL>       <ALL>     <ALL>       Y
 BUILDING   D       M    <ALL>       <ALL>     <ALL>       Y
 ZONES      M       M    <ALL>       <ALL>     <ALL>       Y
SCHEDULES
*SCHEDULE  SEASON  HR   VALUE    HR   VALUE    HR   VALUE    HR   VALUE
*AAAAAAAA AAAAAAAA XX. XXXX.XXX  XX. XXXX.XXX  XX. XXXX.XXX  XX. XXXX.XXX
 HEATING  WINTER   7.   17.      15.    0.
 CR-INT   WINTER   7.    2.45    15.    0.
```

```
 CR-LAT    WINTER     7.     2.       15.     0.
 OFF-INT   WINTER     7.     0.070    15.     0.
 OFF-LAT   WINTER     7.     0.055    15.     0.
 GROUND    OCT        1.    27.4      24.    27.4
 GROUND    NOV        1.    26.7      24.    26.7
 GROUND    DEC        1.    22.1      24.    22.1
 GROUND    JAN        1.    15.9      24.    15.9
 GROUND    FEB        1.     9.2      24.     9.2
 GROUND    MAR        1.     4.3      24.     4.3
SEASONS
* SEASON      START DATE    STOP DATE    DAY OF WEEK
*  NAME         MON DAY       MON DAY    [ALL/M-F/S-S]
*AAAAAAAA       AAA XX.       AAA XX.         AAA
 WINTER         OCT  1.       MAR 31.         ALL
 OCT            OCT  1.       OCT 31.         ALL
 NOV            NOV  1.       NOV 30.         ALL
 DEC            DEC  1.       DEC 31.         ALL
 JAN            JAN  1.       JAN 31.         ALL
 FEB            FEB  1.       FEB 28.         ALL
 MAR            MAR  1.       MAR 31.         ALL
STATIONS
* STATION     LAT. LONG.  ELEV.  FILENAME   DATA  UNITS  -START-   -STOP--
*  NAME      [DEG] [DEG]  [M]               TYPE  [E/M]  MON DAY   MON DAY
*AAAAAAAAAA XX.XX XXX.X XXXXX. AAAAAAAAAA  XX.     A     AAA XX.   AAA XX.
 OCTOBER    35.91  71.8  1475. OCTOBER.R    3.     M     OCT  1.   OCT   30.
 NOVEMBER   35.91  74.3  1469. NOVEMBER.R   3.     M     NOV  1.   NOV   30.
 DECEMBER   35.91  74.3  1469. DECEMBER.R   3.     M     DEC  1.   DEC   31.
 JANUARY    35.91  74.3  1469. JANUARY.R    3.     M     JAN  1.   JAN   31.
 FEBRUARY   35.91  74.3  1469. FEBRUARY.R   3.     M     FEB  1.   FEB   28.
 MARCH      35.91  74.3  1469. MARCH.R      3.     M     MAR  1.   MAR   31.
END OF FILE
```

12.3.1 Alternative Ahmedabad Simulation Scenarios

The following is a list of 16 alternative scenarios that were run for the Ahmedabad School. These scenarios differ only in thermal insulation placement on the walls. Therefore only the Wall Types section of each alternative input file has been included. The first set of eight scenarios utilize R10 insulation and the second set of eight use R5 thermal insulation. The strategies that were simulated were Scenarios 1, 2, 3, 4, 5b, 5, 6 and 7.

```
Scenario 1, R10 insulation applied
R-10 on Ext Walls, winter input for Ahmedabad School, rev. 2/26/96
WALL.TYPES
*   WALL       LAYER     LAYER     LAYER     LAYER     LAYER     LAYER
*   TYPE        # 1       # 2       # 3       # 4       # 5       # 6
*AAAAAAAAAA AAAAAAAAA AAAAAAAAA AAAAAAAAA AAAAAAAAA AAAAAAAAA AAAAAAAAA
 GFLOOR     CONC75    STONE1    R-2.022   <NONE>    <NONE>    <NONE>
 EXT_NW     GYPSMSAND WOOD_LATH INSUL_R10 HCCONCRET <NONE>    <NONE>
 EXT_NE     GYPSMSAND WOOD_LATH INSUL_R10 HCCONCRET <NONE>    <NONE>
 EXT_SW     GYPSMSAND WOOD_LATH INSUL_R10 HCCONCRET <NONE>    <NONE>
 EXT_SE     GYPSMSAND WOOD_LATH INSUL_R10 HCCONCRET <NONE>    <NONE>
 CORRI/OCC  HCCONCRET <NONE>    <NONE>    <NONE>    <NONE>    <NONE>
 SHRD_OCCUP HCCONCRET <NONE>    <NONE>    <NONE>    <NONE>    <NONE>
 CEILING    ROOFMEAS  <NONE>    <NONE>    <NONE>    <NONE>    <NONE>
 CCEILING   ROOFMEAS  <NONE>    <NONE>    <NONE>    <NONE>    <NONE>
 DOOR       WOOD      <NONE>    <NONE>    <NONE>    <NONE>    <NONE>
 WALL       HCCONCRET <NONE>    <NONE>    <NONE>    <NONE>    <NONE>


Scenario 2, R10 insulation applied
R-10 on Ext Walls Except SE, Ahmedabad School, rev. 2/26/96
WALL.TYPES
*   WALL       LAYER     LAYER     LAYER     LAYER     LAYER     LAYER
*   TYPE        # 1       # 2       # 3       # 4       # 5       # 6
*AAAAAAAAAA AAAAAAAAA AAAAAAAAA AAAAAAAAA AAAAAAAAA AAAAAAAAA AAAAAAAAA
 GFLOOR     CONC75    STONE1    R-2.022   <NONE>    <NONE>    <NONE>
 EXT_NW     GYPSMSAND WOOD_LATH INSUL_R10 HCCONCRET <NONE>    <NONE>
```

```
 EXT_NE       GYPSMSAND WOOD_LATH INSUL_R10 HCCONCRET <NONE>    <NONE>
 EXT_SW       GYPSMSAND WOOD_LATH INSUL_R10 HCCONCRET <NONE>    <NONE>
 EXT_SE       HCCONCRET <NONE>    <NONE>    <NONE>    <NONE>    <NONE>
 CORRI/OCC    HCCONCRET <NONE>    <NONE>    <NONE>    <NONE>    <NONE>
 SHRD_OCCUP   HCCONCRET <NONE>    <NONE>    <NONE>    <NONE>    <NONE>
 CEILING      ROOFMEAS  <NONE>    <NONE>    <NONE>    <NONE>    <NONE>
 CCEILING     ROOFMEAS  <NONE>    <NONE>    <NONE>    <NONE>    <NONE>
 DOOR         WOOD      <NONE>    <NONE>    <NONE>    <NONE>    <NONE>
 WALL         HCCONCRET <NONE>    <NONE>    <NONE>    <NONE>    <NONE>
```

```
Scenario 3, R10 insulation applied
R-10 on Ext Walls and Ceiling, winter input for Ahmedabad School, rev. 9/28/96
WALL.TYPES
*   WALL       LAYER     LAYER     LAYER     LAYER     LAYER     LAYER
*   TYPE        # 1       # 2       # 3       # 4       # 5       # 6
*AAAAAAAAAA AAAAAAAAA AAAAAAAAA AAAAAAAAA AAAAAAAAA AAAAAAAAA AAAAAAAAA
 GFLOOR     CONC75    STONE1    R-2.022   <NONE>    <NONE>    <NONE>
 EXT_NW     GYPSMSAND WOOD_LATH INSUL_R10 HCCONCRET <NONE>    <NONE>
 EXT_NE     GYPSMSAND WOOD_LATH INSUL_R10 HCCONCRET <NONE>    <NONE>
 EXT_SW     GYPSMSAND WOOD_LATH INSUL_R10 HCCONCRET <NONE>    <NONE>
 EXT_SE     GYPSMSAND WOOD_LATH INSUL_R10 HCCONCRET <NONE>    <NONE>
 CORRI/OCC  HCCONCRET <NONE>    <NONE>    <NONE>    <NONE>    <NONE>
 SHRD_OCCUP HCCONCRET <NONE>    <NONE>    <NONE>    <NONE>    <NONE>
 CEILING    GYPSMSAND WOOD_LATH INSUL_R10 ROOFMEAS  <NONE>    <NONE>
 CCEILING   ROOFMEAS  <NONE>    <NONE>    <NONE>    <NONE>    <NONE>
 DOOR       WOOD      <NONE>    <NONE>    <NONE>    <NONE>    <NONE>
```

```
Scenario 4, R10 insulation applied
R-10 on Ext & Occ/Corridr walls, Ahmedabad School, rev. 2/26/96
WALL.TYPES
*   WALL       LAYER     LAYER     LAYER     LAYER     LAYER     LAYER
*   TYPE        # 1       # 2       # 3       # 4       # 5       # 6
*AAAAAAAAAA AAAAAAAAA AAAAAAAAA AAAAAAAAA AAAAAAAAA AAAAAAAAA AAAAAAAAA
```

```
 GFLOOR      CONC75    STONE1    R-2.022   <NONE>    <NONE>    <NONE>
 EXT_NW      GYPSMSAND WOOD_LATH INSUL_R10 HCCONCRET <NONE>    <NONE>
 EXT_NE      GYPSMSAND WOOD_LATH INSUL_R10 HCCONCRET <NONE>    <NONE>
 EXT_SW      GYPSMSAND WOOD_LATH INSUL_R10 HCCONCRET <NONE>    <NONE>
 EXT_SE      GYPSMSAND WOOD_LATH INSUL_R10 HCCONCRET <NONE>    <NONE>
 CORRI/OCC   GYPSMSAND WOOD_LATH INSUL_R10 HCCONCRET <NONE>    <NONE>
 SHRD_OCCUP  HCCONCRET <NONE>    <NONE>    <NONE>    <NONE>    <NONE>
 CEILING     ROOFMEAS  <NONE>    <NONE>    <NONE>    <NONE>    <NONE>
 CCEILING    ROOFMEAS  <NONE>    <NONE>    <NONE>    <NONE>    <NONE>
 DOOR        WOOD      <NONE>    <NONE>    <NONE>    <NONE>    <NONE>
 WALL        HCCONCRET <NONE>    <NONE>    <NONE>    <NONE>    <NONE>

Scenario 5b, R10 insulation applied
R-10 on Ext and on both side of shared occupied walls,
winter input for Ahmedabad School, rev. 9/28/96
WALL.TYPES
*   WALL       LAYER     LAYER     LAYER     LAYER     LAYER     LAYER
*   TYPE        # 1       # 2       # 3       # 4       # 5       # 6
*AAAAAAAAAA AAAAAAAAA AAAAAAAAA AAAAAAAAA AAAAAAAAA AAAAAAAAA AAAAAAAAA
 GFLOOR      CONC75    STONE1    R-2.022   <NONE>    <NONE>    <NONE>
 EXT_NW      GYPSMSAND WOOD_LATH INSUL_R10 HCCONCRET <NONE>    <NONE>
 EXT_NE      GYPSMSAND WOOD_LATH INSUL_R10 HCCONCRET <NONE>    <NONE>
 EXT_SW      GYPSMSAND WOOD_LATH INSUL_R10 HCCONCRET <NONE>    <NONE>
 EXT_SE      GYPSMSAND WOOD_LATH INSUL_R10 HCCONCRET <NONE>    <NONE>
 CORRI/OCC   HCCONCRET <NONE>    <NONE>    <NONE>    <NONE>    <NONE>
 SHRD_OCCUP  GYPSMSAND WOOD_LATH INSUL_R10 HCCONCRET INSUL_R10 GYPS_LATH
 CEILING     ROOFMEAS  <NONE>    <NONE>    <NONE>    <NONE>    <NONE>
 CCEILING    ROOFMEAS  <NONE>    <NONE>    <NONE>    <NONE>    <NONE>
 DOOR        WOOD      <NONE>    <NONE>    <NONE>    <NONE>    <NONE>

Scenario 5, R10 insulation applied
R-10 on Ext and R5 on each side of shared occupied walls,
winter input for Ahmedabad School, rev. 9/28/96
WALL.TYPES
```

```
*   WALL       LAYER     LAYER     LAYER     LAYER     LAYER     LAYER
*   TYPE        # 1       # 2       # 3       # 4       # 5       # 6
*AAAAAAAAAA AAAAAAAAA AAAAAAAAA AAAAAAAAA AAAAAAAAA AAAAAAAAA AAAAAAAAA
 GFLOOR     CONC75    STONE1    R-2.022   <NONE>    <NONE>    <NONE>
 EXT_NW     GYPSMSAND WOOD_LATH INSUL_R10 HCCONCRET <NONE>    <NONE>
 EXT_NE     GYPSMSAND WOOD_LATH INSUL_R10 HCCONCRET <NONE>    <NONE>
 EXT_SW     GYPSMSAND WOOD_LATH INSUL_R10 HCCONCRET <NONE>    <NONE>
 EXT_SE     GYPSMSAND WOOD_LATH INSUL_R10 HCCONCRET <NONE>    <NONE>
 CORRI/OCC  HCCONCRET <NONE>    <NONE>    <NONE>    <NONE>    <NONE>
 SHRD_OCCUP GYPSMSAND WOOD_LATH INSUL_R5  HCCONCRET INSUL_R5  GYPS_LATH
 CEILING    ROOFMEAS  <NONE>    <NONE>    <NONE>    <NONE>    <NONE>
 CCEILING   ROOFMEAS  <NONE>    <NONE>    <NONE>    <NONE>    <NONE>
 DOOR       WOOD      <NONE>    <NONE>    <NONE>    <NONE>    <NONE>
```

Scenario 6, R10 insulation applied
R-10 on Ext, Shared Walls, and Ceiling, winter input for Ahmedabad School, rev. 9/28/96


```
WALL.TYPES
*   WALL       LAYER     LAYER     LAYER     LAYER     LAYER     LAYER
*   TYPE        # 1       # 2       # 3       # 4       # 5       # 6
*AAAAAAAAAA AAAAAAAAA AAAAAAAAA AAAAAAAAA AAAAAAAAA AAAAAAAAA AAAAAAAAA
 GFLOOR     CONC75    STONE1    R-2.022   <NONE>    <NONE>    <NONE>
 EXT_NW     GYPSMSAND WOOD_LATH INSUL_R10 HCCONCRET <NONE>    <NONE>
 EXT_NE     GYPSMSAND WOOD_LATH INSUL_R10 HCCONCRET <NONE>    <NONE>
 EXT_SW     GYPSMSAND WOOD_LATH INSUL_R10 HCCONCRET <NONE>    <NONE>
 EXT_SE     GYPSMSAND WOOD_LATH INSUL_R10 HCCONCRET <NONE>    <NONE>
 CORRI/OCC  HCCONCRET <NONE>    <NONE>    <NONE>    <NONE>    <NONE>
 SHRD_OCCUP GYPSMSAND WOOD_LATH INSUL_R5  HCCONCRET INSUL_R5  GYPS_LATH
 CEILING    GYPSMSAND WOOD_LATH INSUL_R10 ROOFMEAS  <NONE>    <NONE>
 CCEILING   ROOFMEAS  <NONE>    <NONE>    <NONE>    <NONE>    <NONE>
 DOOR       WOOD      <NONE>    <NONE>    <NONE>    <NONE>    <NONE>
```

Scenario 7, R10 insulation applied
R-10 on occ. side of ext and corridor walls and ceiling, winter input for Ahmedabad School, rev. 9/28/96

```
WALL.TYPES
*   WALL       LAYER     LAYER     LAYER     LAYER     LAYER     LAYER
*   TYPE        # 1       # 2       # 3       # 4       # 5       # 6
*AAAAAAAAAA AAAAAAAAA AAAAAAAAA AAAAAAAAA AAAAAAAAA AAAAAAAAA AAAAAAAAA
 GFLOOR      CONC75    STONE1    R-2.022   <NONE>    <NONE>    <NONE>
 EXT_NW      GYPSMSAND WOOD_LATH INSUL_R10 HCCONCRET <NONE>    <NONE>
 EXT_NE      GYPSMSAND WOOD_LATH INSUL_R10 HCCONCRET <NONE>    <NONE>
 EXT_SW      GYPSMSAND WOOD_LATH INSUL_R10 HCCONCRET <NONE>    <NONE>
 EXT_SE      GYPSMSAND WOOD_LATH INSUL_R10 HCCONCRET <NONE>    <NONE>
 CORRI/OCC   GYPSMSAND WOOD_LATH INSUL_R10 HCCONCRET <NONE>    <NONE>
 SHRD_OCCUP  HCCONCRET <NONE>    <NONE>    <NONE>    <NONE>    <NONE>
 CEILING     GYPSMSAND WOOD_LATH INSUL_R10 ROOFMEAS  <NONE>    <NONE>
 CCEILING    ROOFMEAS  <NONE>    <NONE>    <NONE>    <NONE>    <NONE>
 DOOR        WOOD      <NONE>    <NONE>    <NONE>    <NONE>    <NONE>
```

Scenario 1, R5 insulation applied

```
R-5 on Ext Walls, winter input for Ahmedabad School, rev. 2/26/96
WALL.TYPES
*   WALL       LAYER     LAYER     LAYER     LAYER     LAYER     LAYER
*   TYPE        # 1       # 2       # 3       # 4       # 5       # 6
*AAAAAAAAAA AAAAAAAAA AAAAAAAAA AAAAAAAAA AAAAAAAAA AAAAAAAAA AAAAAAAAA
 GFLOOR      CONC75    STONE1    R-2.022   <NONE>    <NONE>    <NONE>
 EXT_NW      GYPSMSAND WOOD_LATH INSUL_R5  HCCONCRET <NONE>    <NONE>
 EXT_NE      GYPSMSAND WOOD_LATH INSUL_R5  HCCONCRET <NONE>    <NONE>
 EXT_SW      GYPSMSAND WOOD_LATH INSUL_R5  HCCONCRET <NONE>    <NONE>
 EXT_SE      GYPSMSAND WOOD_LATH INSUL_R5  HCCONCRET <NONE>    <NONE>
 CORRI/OCC   HCCONCRET <NONE>    <NONE>    <NONE>    <NONE>    <NONE>
 SHRD_OCCUP  HCCONCRET <NONE>    <NONE>    <NONE>    <NONE>    <NONE>
 CEILING     ROOFMEAS  <NONE>    <NONE>    <NONE>    <NONE>    <NONE>
 CCEILING    ROOFMEAS  <NONE>    <NONE>    <NONE>    <NONE>    <NONE>
 DOOR        WOOD      <NONE>    <NONE>    <NONE>    <NONE>    <NONE>
 WALL        HCCONCRET <NONE>    <NONE>    <NONE>    <NONE>    <NONE>
```

Scenario 2, R5 insulation applied

```
R-5 on Ext Walls Except SE, Ahmedabad School, rev. 2/26/96
WALL.TYPES
*   WALL       LAYER     LAYER     LAYER     LAYER     LAYER     LAYER
*   TYPE        # 1       # 2       # 3       # 4       # 5       # 6
*AAAAAAAAAA AAAAAAAAA AAAAAAAAA AAAAAAAAA AAAAAAAAA AAAAAAAAA AAAAAAAAA
 GFLOOR     CONC75    STONE1    R-2.022   <NONE>    <NONE>    <NONE>
 EXT_NW     GYPSMSAND WOOD_LATH INSUL_R5  HCCONCRET <NONE>    <NONE>
 EXT_NE     GYPSMSAND WOOD_LATH INSUL_R5  HCCONCRET <NONE>    <NONE>
 EXT_SW     GYPSMSAND WOOD_LATH INSUL_R5  HCCONCRET <NONE>    <NONE>
 EXT_SE     HCCONCRET <NONE>    <NONE>    <NONE>    <NONE>    <NONE>
 CORRI/OCC  HCCONCRET <NONE>    <NONE>    <NONE>    <NONE>    <NONE>
 SHRD_OCCUP HCCONCRET <NONE>    <NONE>    <NONE>    <NONE>    <NONE>
 CEILING    ROOFMEAS  <NONE>    <NONE>    <NONE>    <NONE>    <NONE>
 CCEILING   ROOFMEAS  <NONE>    <NONE>    <NONE>    <NONE>    <NONE>
 DOOR       WOOD      <NONE>    <NONE>    <NONE>    <NONE>    <NONE>
 WALL       HCCONCRET <NONE>    <NONE>    <NONE>    <NONE>    <NONE>

Scenario 3, R5 insulation applied
R-5 on Ext Walls and Ceiling, winter input for Ahmedabad School, rev. 9/28/96
WALL.TYPES
*   WALL       LAYER     LAYER     LAYER     LAYER     LAYER     LAYER
*   TYPE        # 1       # 2       # 3       # 4       # 5       # 6
*AAAAAAAAAA AAAAAAAAA AAAAAAAAA AAAAAAAAA AAAAAAAAA AAAAAAAAA AAAAAAAAA
 GFLOOR     CONC75    STONE1    R-2.022   <NONE>    <NONE>    <NONE>
 EXT_NW     GYPSMSAND WOOD_LATH INSUL_R5  HCCONCRET <NONE>    <NONE>
 EXT_NE     GYPSMSAND WOOD_LATH INSUL_R5  HCCONCRET <NONE>    <NONE>
 EXT_SW     GYPSMSAND WOOD_LATH INSUL_R5  HCCONCRET <NONE>    <NONE>
 EXT_SE     GYPSMSAND WOOD_LATH INSUL_R5  HCCONCRET <NONE>    <NONE>
 CORRI/OCC  HCCONCRET <NONE>    <NONE>    <NONE>    <NONE>    <NONE>
 SHRD_OCCUP HCCONCRET <NONE>    <NONE>    <NONE>    <NONE>    <NONE>
 CEILING    GYPSMSAND WOOD_LATH INSUL_R5  ROOFMEAS  <NONE>    <NONE>
 CCEILING   ROOFMEAS  <NONE>    <NONE>    <NONE>    <NONE>    <NONE>
 DOOR       WOOD      <NONE>    <NONE>    <NONE>    <NONE>    <NONE>
```

```
Scenario 4, R5 insulation applied
R-5 on Ext & Occ/Corridr walls, Ahmedabad School, rev. 2/26/96
WALL.TYPES
*   WALL       LAYER     LAYER     LAYER     LAYER     LAYER     LAYER
*   TYPE        # 1       # 2       # 3       # 4       # 5       # 6
*AAAAAAAAAA AAAAAAAAA AAAAAAAAA AAAAAAAAA AAAAAAAAA AAAAAAAAA AAAAAAAAA
 GFLOOR     CONC75    STONE1    R-2.022   <NONE>    <NONE>    <NONE>
 EXT_NW     GYPSMSAND WOOD_LATH INSUL_R5  HCCONCRET <NONE>    <NONE>
 EXT_NE     GYPSMSAND WOOD_LATH INSUL_R5  HCCONCRET <NONE>    <NONE>
 EXT_SW     GYPSMSAND WOOD_LATH INSUL_R5  HCCONCRET <NONE>    <NONE>
 EXT_SE     GYPSMSAND WOOD_LATH INSUL_R5  HCCONCRET <NONE>    <NONE>
 CORRI/OCC  GYPSMSAND WOOD_LATH INSUL_R5  HCCONCRET <NONE>    <NONE>
 SHRD_OCCUP HCCONCRET <NONE>    <NONE>    <NONE>    <NONE>    <NONE>
 CEILING    ROOFMEAS  <NONE>    <NONE>    <NONE>    <NONE>    <NONE>
 CCEILING   ROOFMEAS  <NONE>    <NONE>    <NONE>    <NONE>    <NONE>
 DOOR       WOOD      <NONE>    <NONE>    <NONE>    <NONE>    <NONE>
 WALL       HCCONCRET <NONE>    <NONE>    <NONE>    <NONE>    <NONE>
```

```
Scenario 5b, R5 insulation applied
on Ext and on both sides of shared occupied walls,
winter input for Ahmedabad School, rev. 9/28/96
WALL.TYPES
*   WALL       LAYER     LAYER     LAYER     LAYER     LAYER     LAYER
*   TYPE        # 1       # 2       # 3       # 4       # 5       # 6
*AAAAAAAAAA AAAAAAAAA AAAAAAAAA AAAAAAAAA AAAAAAAAA AAAAAAAAA AAAAAAAAA
 GFLOOR     CONC75    STONE1    R-2.022   <NONE>    <NONE>    <NONE>
 EXT_NW     GYPSMSAND WOOD_LATH INSUL_R5  HCCONCRET <NONE>    <NONE>
 EXT_NE     GYPSMSAND WOOD_LATH INSUL_R5  HCCONCRET <NONE>    <NONE>
 EXT_SW     GYPSMSAND WOOD_LATH INSUL_R5  HCCONCRET <NONE>    <NONE>
 EXT_SE     GYPSMSAND WOOD_LATH INSUL_R5  HCCONCRET <NONE>    <NONE>
 CORRI/OCC  HCCONCRET <NONE>    <NONE>    <NONE>    <NONE>    <NONE>
 SHRD_OCCUP GYPSMSAND WOOD_LATH INSUL_R5  HCCONCRET INSUL_R5  GYPS_LATH
 CEILING    ROOFMEAS  <NONE>    <NONE>    <NONE>    <NONE>    <NONE>
 CCEILING   ROOFMEAS  <NONE>    <NONE>    <NONE>    <NONE>    <NONE>
```

```
DOOR        WOOD      <NONE>    <NONE>    <NONE>    <NONE>    <NONE>
```

```
Scenario 5, R5 insulation applied
R-5 on Ext and Shared Walls, winter input for Ahmedabad School, rev. 9/28/96
WALL.TYPES
*   WALL      LAYER     LAYER     LAYER     LAYER     LAYER     LAYER
*   TYPE       # 1       # 2       # 3       # 4       # 5       # 6
*AAAAAAAAAA AAAAAAAAA AAAAAAAAA AAAAAAAAA AAAAAAAAA AAAAAAAAA AAAAAAAAA
 GFLOOR     CONC75    STONE1    R-2.022   <NONE>    <NONE>    <NONE>
 EXT_NW     GYPSMSAND WOOD_LATH INSUL_R5  HCCONCRET <NONE>    <NONE>
 EXT_NE     GYPSMSAND WOOD_LATH INSUL_R5  HCCONCRET <NONE>    <NONE>
 EXT_SW     GYPSMSAND WOOD_LATH INSUL_R5  HCCONCRET <NONE>    <NONE>
 EXT_SE     GYPSMSAND WOOD_LATH INSUL_R5  HCCONCRET <NONE>    <NONE>
 CORRI/OCC  HCCONCRET <NONE>    <NONE>    <NONE>    <NONE>    <NONE>
 SHRD_OCCUP GYPSMSAND WOOD_LATH INSL_R2.5 HCCONCRET INSL_R2.5 GYPS_LATH
 CEILING    ROOFMEAS  <NONE>    <NONE>    <NONE>    <NONE>    <NONE>
 CCEILING   ROOFMEAS  <NONE>    <NONE>    <NONE>    <NONE>    <NONE>
 DOOR       WOOD      <NONE>    <NONE>    <NONE>    <NONE>    <NONE>
```

```
Scenario 6, R5 insulation applied
R-5 on Ext,Shared Walls, and Ceiling, winter input for Ahmedabad School, rev. 9/28/96
WALL.TYPES
*   WALL      LAYER     LAYER     LAYER     LAYER     LAYER     LAYER
*   TYPE       # 1       # 2       # 3       # 4       # 5       # 6
*AAAAAAAAAA AAAAAAAAA AAAAAAAAA AAAAAAAAA AAAAAAAAA AAAAAAAAA AAAAAAAAA
 GFLOOR     CONC75    STONE1    R-2.022   <NONE>    <NONE>    <NONE>
 EXT_NW     GYPSMSAND WOOD_LATH INSUL_R5  HCCONCRET <NONE>    <NONE>
 EXT_NE     GYPSMSAND WOOD_LATH INSUL_R5  HCCONCRET <NONE>    <NONE>
 EXT_SW     GYPSMSAND WOOD_LATH INSUL_R5  HCCONCRET <NONE>    <NONE>
 EXT_SE     GYPSMSAND WOOD_LATH INSUL_R5  HCCONCRET <NONE>    <NONE>
 CORRI/OCC  HCCONCRET <NONE>    <NONE>    <NONE>    <NONE>    <NONE>
 SHRD_OCCUP GYPSMSAND WOOD_LATH INSL_R2.5 HCCONCRET INSL_R2.5 GYPS_LATH
 CEILING    GYPSMSAND WOOD_LATH INSUL_R5  ROOFMEAS  <NONE>    <NONE>
 CCEILING   ROOFMEAS  <NONE>    <NONE>    <NONE>    <NONE>    <NONE>
```

```
 DOOR        WOOD       <NONE>    <NONE>    <NONE>          <NONE>    <NONE>

Scenario 7, R5 insulation applied
R-5 on occ. side of ext and corridor walls and ceiling, winter input for Ahmedabad
School, rev. 9/28/96
WALL.TYPES
*   WALL      LAYER     LAYER     LAYER     LAYER     LAYER     LAYER
*   TYPE       # 1       # 2       # 3       # 4       # 5       # 6
*AAAAAAAAAA AAAAAAAAA AAAAAAAAA AAAAAAAAA AAAAAAAAA AAAAAAAAA AAAAAAAAA
 GFLOOR     CONC75    STONE1    R-2.022   <NONE>    <NONE>    <NONE>
 EXT_NW     GYPSMSAND WOOD_LATH INSUL_R5  HCCONCRET <NONE>    <NONE>
 EXT_NE     GYPSMSAND WOOD_LATH INSUL_R5  HCCONCRET <NONE>    <NONE>
 EXT_SW     GYPSMSAND WOOD_LATH INSUL_R5  HCCONCRET <NONE>    <NONE>
 EXT_SE     GYPSMSAND WOOD_LATH INSUL_R5  HCCONCRET <NONE>    <NONE>
 CORRI/OCC  GYPSMSAND WOOD_LATH INSUL_R5  HCCONCRET <NONE>    <NONE>
 SHRD_OCCUP HCCONCRET <NONE>    <NONE>    <NONE>    <NONE>    <NONE>
 CEILING    GYPSMSAND WOOD_LATH INSUL_R5  ROOFMEAS  <NONE>    <NONE>
 CCEILING   ROOFMEAS  <NONE>    <NONE>    <NONE>    <NONE>    <NONE>
 DOOR       WOOD      <NONE>    <NONE>    <NONE>    <NONE>    <NONE>
```

12.4 Parvak baseline condition winter input file, revised 9/30/96

```
RUNS
*     RUN LABEL      STATION    GROUND  GROUND -START- -STOP-- SKYLINE  PAR.
*                     NAME       REFL.   TEMP. MON DAY MON DAY PROFILE  TYPE
*                               [FRAC]    [C]  [DATE]  [DATE]
*AAAAAAAAAAAAAAAA AAAAAAAAAA S.SSSS SSS.SS AAA XX. AAA XX. AAAAAA   AAAAAA
 PARVAK1          OCTOBER    0.2000 GROUND OCT  1. OCT 25. SKY      <NONE>
 PARVAK1          NOVEMBER   0.2000 GROUND NOV  1. NOV 25. SKY      <NONE>
 PARVAK1          DECEMBER   0.2000 GROUND DEC  1. DEC 25. SKY      <NONE>
 PARVAK1          JANUARY    0.2000 GROUND JAN  1. JAN 25. SKY      <NONE>
 PARVAK1          FEBRUARY   0.2000 GROUND FEB  1. FEB 25. SKY      <NONE>
 PARVAK1          MARCH      0.2000 GROUND MAR  1. MAR 25. SKY      <NONE>
ZONES
*   ZONE        HVAC       FLOOR   HGT   INFIL.  SOLAR   SOLAR INTERNAL  LATENT
*   NAME        TYPE       AREA           RATE  TO AIR   LOST    GAIN     GAIN
*                          [SM]    [M]  [AC/H] [FRAC]  [FRAC]    [KW]     [KW]
*AAAAAAAAAA AAAAAAAAAA XXXXX.X XX.X SSS.SSS X.XXX   X.XXX SSSS.SSS SSSS.SSS
 CLASSROOM1 WOODSTOVE     35.7  3.2    1.37  0.15    0.04 CR-INT   CR-LAT
 CLASSROOM2 WOODSTOVE     35.7  3.2    1.37  0.15    0.04 CR-INT   CR-LAT
 CLASSROOM3 WOODSTOVE     35.7  3.2    1.37  0.15    0.04 CR-INT   CR-LAT
 OFFICE     WOODSTOVE     23.8  3.2    1.37  0.15    0.03 OF-INT   OF-LAT
 CORRIDOR   <NONE>        25.3  3.2    1.37  0.15    0.05     0.       0.
WINDOWS
* INTERIOR   EXTERIOR   GLAZING    HEIGHT LENGTH --LOCATION--  EXTERIOR
*   ZONE     SURFACE     TYPE                     HORZ.   VERT.   ZONE
*                                    [M]     [M]    [M]     [M]
*AAAAAAAAAA AAAAAAAAAA AAAAAAAAAA XXX.XX XXX.XX XXXX.XX XXXX.XX AAAAAAAAAA
 CLASSROOM1 SOUTHEAST  DOUBLE       1.22   1.01    1.02    0.61 AMBIENT
 CLASSROOM1 SOUTHEAST  DOUBLE       1.22   1.01    3.45    0.61 AMBIENT
 CLASSROOM1 SOUTHEAST  DOUBLE       1.22   1.01    5.88    0.61 AMBIENT
 CLASSROOM1 SESKY      FIBERGLAS    0.61   2.44    2.44    4.27 AMBIENT
 CLASSROOM2 NORTHWEST  DOUBLE       1.22   1.01    0.81    0.61 AMBIENT
 CLASSROOM2 NORTHWEST  DOUBLE       1.22   1.01    3.24    0.61 AMBIENT
```

```
 CLASSROOM2 NORTHWEST  DOUBLE      1.22   1.01    5.67    0.61 AMBIENT
 CLASSROOM2 NWSKY      FIBERGLAS   0.61   2.44    2.44    0.   AMBIENT
 CLASSROOM3 NORTHEAST  DOUBLE      1.22   1.01    1.02    0.61 AMBIENT
 CLASSROOM3 NORTHEAST  DOUBLE      1.22   1.01    3.45    0.61 AMBIENT
 CLASSROOM3 NORTHEAST  DOUBLE      1.22   1.01    5.88    0.61 AMBIENT
 CLASSROOM3 NWSKY      FIBERGLAS   2.44   0.61    0.      2.44 AMBIENT
 OFFICE     NORTHEAST  DOUBLE      1.22   1.01    0.71    0.61 AMBIENT
 CORRIDOR   NWSKY      FIBERGLAS   0.61   2.44    0.      4.58 AMBIENT
 CORRIDOR   SESKY      FIBERGLAS   0.61   2.44    0.      3.97 AMBIENT
 CORRIDOR   NORTHWEST  SINGLE      1.64   1.64    0.      0.   AMBIENT
 CORRIDOR   SOUTHEAST  SINGLE      1.64   1.64    0.      0.   AMBIENT
WALLS
*   WALL      --FRONT/INTERIOR SIDE--  --BACK/EXTERIOR SIDE---   WALL
*   TYPE        ZONE      SURF   SOLAR  ZONE OR     SURF  SOLAR    AREA
*               NAME      COEF   COEF.  SURFACE,    COEF  COEF.
*                         [W/C  [FRAC]  AMBIENT,    [W/C  [FRAC]   [SM]
*                         -SM]          GROUND      -SM]
*AAAAAAAAAA AAAAAAAAAA XX.XXX X.XXXX AAAAAAAAAA XX.XXX X.XXXX  XXXXX.X
 ROOF       CORRIDOR    8.278 <AREA> NWSKY      22.7   <AREA>     12.7
 ROOF       CORRIDOR    8.278 <AREA> SESKY      22.7   <AREA>     12.7
 ROOF       CLASSROOM1  8.278 <AREA> SESKY      22.7   <AREA>     35.7
 ROOF       CLASSROOM2  8.278 <AREA> NWSKY      22.7   <AREA>     35.7
 ROOF       CLASSROOM3  8.278 <AREA> NWSKY      22.7   <AREA>     23.8
 ROOF       CLASSROOM3  8.278 <AREA> SESKY      22.7   <AREA>     11.9
 ROOF       OFFICE      8.278 <AREA> SESKY      22.7   <AREA>     11.9
 EXT_SE     CLASSROOM1  8.278 <AREA> SOUTHEAST  18.2   <AREA>     19.8
 EXT_SW     CLASSROOM1  8.278 <AREA> SOUTHWEST  18.2   <AREA>     13.2
 SHRD_OCCUP CLASSROOM1  8.278 <AREA> CLASSROOM2  8.278 <AREA>     19.8
 CORRI/OCC  CLASSROOM1  8.278 <AREA> CORRIDOR    8.278 <AREA>     11.2
 DOOR       CLASSROOM1  8.278 <AREA> CORRIDOR    8.278 <AREA>      2.
 EXT_SW     CLASSROOM2  8.278 <AREA> SOUTHWEST  18.2   <AREA>     13.2
 EXT_NW     CLASSROOM2  8.278 <AREA> NORTHWEST  18.2   <AREA>     19.8
 CORRI/OCC  CLASSROOM2  8.278 <AREA> CORRIDOR    8.278 <AREA>     11.2
```

```
 DOOR        CLASSROOM2  8.278 <AREA> CORRIDOR    8.278 <AREA>      2.
 EXT_NW      CLASSROOM3  8.278 <AREA> NORTHWEST  18.2   <AREA>     13.2
 EXT_NE      CLASSROOM3  8.278 <AREA> NORTHEAST  18.2   <AREA>     19.8
 SHRD_OCCUP  CLASSROOM3  8.278 <AREA> OFFICE      8.278 <AREA>     13.2
 CORRI/OCC   CLASSROOM3  8.278 <AREA> CORRIDOR    8.278 <AREA>     17.8
 DOOR        CLASSROOM3  8.278 <AREA> CORRIDOR    8.278 <AREA>      2.
 EXT_NE      OFFICE      8.278 <AREA> NORTHEAST  18.2   <AREA>      6.6
 EXT_SE      OFFICE      8.278 <AREA> SOUTHEAST  18.2   <AREA>     13.2
 CORRI/OCC   OFFICE      8.278 <AREA> CORRIDOR    8.278 <AREA>      4.6
 DOOR        OFFICE      8.278 <AREA> CORRIDOR    8.278 <AREA>      2.
 DOOR        CORRIDOR    8.278 <AREA> NORTHWEST  18.2   <AREA>      6.7
 DOOR        CORRIDOR    8.278 <AREA> SOUTHEAST  18.2   <AREA>      6.7
 GFLOOR      CORRIDOR    8.278 <AREA> GROUND     99.99  <AREA>     25.3
 GFLOOR      CLASSROOM1  8.278 <AREA> GROUND     99.99  <AREA>     35.7
 GFLOOR      CLASSROOM2  8.278 <AREA> GROUND     99.99  <AREA>     35.7
 GFLOOR      CLASSROOM3  8.278 <AREA> GROUND     99.99  <AREA>     35.7
 GFLOOR      OFFICE      8.278 <AREA> GROUND     99.99  <AREA>     11.9
SURFACES
*  SURFACE   COMPASS   TILT  HEIGHT  LENGTH  ---------  SHADING  ---------
*            AZIMUTH                          PARALLEL   LEFT        RIGHT
*                                               TYPE     PERPEND     PERPEND
*             [DEG]   [DEG]    [M]      [M]
*AAAAAAAAAA   XXX.X    XX.X XXXX.XX XXXX.XX AAAAAAAAAA AAAAAAAAAA AAAAAAAAAA
 NORTHWEST    278.     90.      3.2     10.9 <NONE>     <NONE>     <NONE>
 NORTHEAST      8.     90.      3.2     16.2 <NONE>     <NONE>     <NONE>
 SOUTHEAST     98.     90.      3.2     10.9 <NONE>     <NONE>     <NONE>
 SOUTHWEST    188.     90.      3.2     16.2 <NONE>     <NONE>     <NONE>
 NWSKY        278.     28.8     6.22    16.2 <NONE>     <NONE>     <NONE>
 SESKY         98.     28.8     6.22    16.2 <NONE>     <NONE>     <NONE>
HVAC.TYPES
*    HVAC    HEATING  VENTING  COOLING  HEATING  VENTING  COOLING COOLER
*    TYPE    SETPOINT SETPOINT SETPOINT CAPACITY CAPACITY CAPACITY         COIL
*              [C]      [C]      [C]      [KW]    [AC/H]    [KW]       [C]
```

```
*AAAAAAAAAA SSS.SSS  SSS.SSS  SSS.SSS  XXXX.XXX  XXX.XX  XXXX.XXX          XX.X
 WOODSTOVE  HEATING  <NONE>   <NONE>   <ADEQ>      0.       0.         12.8
WALL.TYPES
*   WALL       LAYER     LAYER     LAYER     LAYER     LAYER     LAYER
*   TYPE        # 1       # 2       # 3       # 4       # 5       # 6
*AAAAAAAAAA AAAAAAAAA AAAAAAAAA AAAAAAAAA AAAAAAAAA AAAAAAAAA AAAAAAAAA
 DOOR       WOOD      <NONE>    <NONE>    <NONE>    <NONE>    <NONE>
 CORRI/OCC  TRCRETE   <NONE>    <NONE>    <NONE>    <NONE>    <NONE>
 SHRD_OCCUP TRCRETE   <NONE>    <NONE>    <NONE>    <NONE>    <NONE>
 EXT_NW     TRCRETE   <NONE>    <NONE>    <NONE>    <NONE>    <NONE>
 EXT_NE     TRCRETE   <NONE>    <NONE>    <NONE>    <NONE>    <NONE>
 EXT_SW     TRCRETE   <NONE>    <NONE>    <NONE>    <NONE>    <NONE>
 EXT_SE     TRCRETE   <NONE>    <NONE>    <NONE>    <NONE>    <NONE>
 ROOF       CEILING   <NONE>    <NONE>    <NONE>    <NONE>    <NONE>
 GFLOOR     CONC75    STONE1    R-2.022   <NONE>    <NONE>    <NONE>
MASS.TYPES
*MASS TYPE   CONDUCTIVITY   DENSITY    SPECIFIC HEAT  THICKNESS  NODES
*              [W/M-C]      [KG/CM]     [KJ/KG-C]       [M]
*AAAAAAAAAA    X.XXXX      XXXX.XXX      X.XXXX       XX.XXXX    XX.
 CONC75        1.4         2100.         0.653          0.0762    1.
 STONE1        1.73        2242.         0.837          0.127     1.
 WOOD          0.115        513.         2.64           0.0127    1.
 CEILING       0.055        550.         1.0            0.127     1.
 TRCRETE       1.002       2253.         1.7335         0.300     1.
 INSUL_R5      0.0288        98.         1.339          0.0254    1.
 INSUL_R10     0.0288        98.         1.339          0.0508    1.
 GYPSMSAND     0.7999      1682.         0.8368         0.0127    1.
 WOOD_LATH     0.115        513.         2.64           0.0064    1.
GLAZING.TYPES
* GLAZING     GLAZING    SHADING EXTINCTION  INDEX OF  THICKNESS  NUMBER
*  TYPE       U VALUE     COEF.     COEF.   REFRACTION OF LAYER     OF
*            [W/SM-C]    [FRAC]    [1/MM]     [NONE]     [MM]     LAYERS
*AAAAAAAAAA  SS.SSSSS   SS.SSSSS  X.XXXX     X.XXXX    X.XXXX      XX.
```

```
 SINGLE        5.67      0.9      0.0197     1.5260    3.1750        1.
 DOUBLE        2.78      0.88     0.0197     1.5260    3.1750        2.
 FIBERGLAS     5.67      0.74     0.0197     1.5260    3.1750        1.
SKYLINE.TYPES
*SKYLINE  --------- ALTITUDE ANGLE OF SKYLINE [DEGREES] -------*PROFILE  ---EAST----------
--------SOUTH-----------------WEST---
* NAME    100   80   60   40   20    0   20   40   60   80   100
*AAAAAA   XX.X XX.X XX.X XX.X XX.X XX.X XX.X XX.X XX.X XX.X XX.X
 SKY       0.   14.  23.  29.  37.  35.  33.  28.  38.  35.   0.
OUTPUTS
* OUTPUT   TIME   UNITS   OUTPUT   BUILDING   OUTPUT   FORMAT?
*  TYPE   PERIOD          SEASON   ELEMENT    SECTION
*         [H/D/M] [E/M]                                 [Y/N]
*AAAAAAAA    A      A    AAAAAAAA    XXXX.     XXXX.      A
 AMBIENT     M      M    <ALL>       <ALL>     <ALL>      Y
 BUILDING    D      M    <ALL>       <ALL>     <ALL>      Y
 ZONES       M      M    <ALL>       <ALL>     <ALL>      Y
SCHEDULES
*SCHEDULE  SEASON  HR   VALUE     HR   VALUE     HR   VALUE     HR   VALUE
*AAAAAAAA AAAAAAAA XX. XXXX.XXX  XX. XXXX.XXX  XX. XXXX.XXX  XX. XXXX.XXX
 HEATING  WINTER    7.   17.      15.    0.
 CR-INT   WINTER    7.    2.45    15.    0.
 CR-LAT   WINTER    7.    2.      15.    0.
 OF-INT   WINTER    7.    0.070   15.    0.
 OF-LAT   WINTER    7.    0.055   15.    0.
 GROUND   OCT       1.   28.1     24.   27.4
 GROUND   NOV       1.   26.7     24.   26.7
 GROUND   DEC       1.   22.2     24.   22.1
 GROUND   JAN       1.   16.2     24.   15.9
 GROUND   FEB       1.   10.7     24.    9.2
 GROUND   MAR       1.    5.6     24.    4.3
SEASONS
* SEASON     START DATE    STOP DATE    DAY OF WEEK
```

```
*  NAME           MON DAY       MON DAY    [ALL/M-F/S-S]
*AAAAAAAA         AAA XX.       AAA XX.         AAA
 WINTER           OCT  1.       MAR 31.         ALL
 OCT              OCT  1.       OCT 31.         ALL
 NOV              NOV  1.       NOV 30.         ALL
 DEC              DEC  1.       DEC 31.         ALL
 JAN              JAN  1.       JAN 31.         ALL
 FEB              FEB  1.       FEB 28.         ALL
 MAR              MAR  1.       MAR 31.         ALL
STATIONS
* STATION      LAT. LONG.  ELEV.  FILENAME   DATA  UNITS  -START-  -STOP--
*  NAME       [DEG] [DEG]  [M]               TYPE  [E/M]  MON DAY  MON DAY
*AAAAAAAAAA XX.XX XXX.X XXXXX. AAAAAAAAAA  XX.     A    AAA XX.  AAA XX.
 OCTOBER     35.91  71.8  1475. OCTCHTRL.R   3.     M    OCT  1.  OCT   30.
 NOVEMBER    35.91  71.8  1475. NOVCHTRL.R   3.     M    NOV  1.  NOV   30.
 DECEMBER    35.91  71.8  1475. DECCHTRL.R   3.     M    DEC  1.  DEC   30.
 JANUARY     35.91  71.8  1475. JANCHTRL.R   3.     M    JAN  1.  JAN   30.
 FEBRUARY    35.91  71.8  1475. FEBCHTRL.R   3.     M    FEB  1.  FEB   28.
 MARCH       35.91  71.8  1475. MARCHTRL.R   3.     M    MAR  1.  MAR   30.
END OF FILE
```

12.4.1 Alternative Parvak Simulation Scenarios

The following is a list of 10 alternative scenarios that were run for the Parvak School. These scenarios differ only in thermal insulation placement on the walls. Therefore only the Wall Types section of each alternative input file has been included. The first set of five scenarios utilize R10 insulation and the second set of five use R5 thermal insulation. Scenarios 1, 2, 3, 4, 7 were simulated.

```
Scenario 1, R10 insulation applied
R-10 on Ext Walls, winter input for the Parvak School, rev. 05/15/96
WALL.TYPES
*    WALL       LAYER      LAYER      LAYER      LAYER      LAYER      LAYER
*    TYPE        # 1        # 2        # 3        # 4        # 5        # 6
```

```
*AAAAAAAAAA AAAAAAAAA AAAAAAAAA AAAAAAAAA AAAAAAAAA AAAAAAAAA AAAAAAAAA
 DOOR       WOOD      <NONE>    <NONE>    <NONE>    <NONE>    <NONE>
 CORRI/OCC  TRCRETE   <NONE>    <NONE>    <NONE>    <NONE>    <NONE>
 SHRD_OCCUP TRCRETE   <NONE>    <NONE>    <NONE>    <NONE>    <NONE>
 EXT_NW     GYPSMSAND WOOD_LATH INSUL_R10 TRCRETE   <NONE>    <NONE>
 EXT_NE     GYPSMSAND WOOD_LATH INSUL_R10 TRCRETE   <NONE>    <NONE>
 EXT_SW     GYPSMSAND WOOD_LATH INSUL_R10 TRCRETE   <NONE>    <NONE>
 EXT_SE     GYPSMSAND WOOD_LATH INSUL_R10 TRCRETE   <NONE>    <NONE>
 ROOF       CEILING   <NONE>    <NONE>    <NONE>    <NONE>    <NONE>
 GFLOOR     CONC75    STONE1    R-2.022   <NONE>    <NONE>    <NONE>
```

```
Scenario 2, R10 insulation applied
R-10 on Ext Walls Except SE, Parvak School, rev. 05/15/96
WALL.TYPES
*   WALL      LAYER     LAYER     LAYER     LAYER     LAYER     LAYER
*   TYPE       # 1       # 2       # 3       # 4       # 5       # 6
*AAAAAAAAAA AAAAAAAAA AAAAAAAAA AAAAAAAAA AAAAAAAAA AAAAAAAAA AAAAAAAAA
 DOOR       WOOD      <NONE>    <NONE>    <NONE>    <NONE>    <NONE>
 CORRI/OCC  TRCRETE   <NONE>    <NONE>    <NONE>    <NONE>    <NONE>
 SHRD_OCCUP TRCRETE   <NONE>    <NONE>    <NONE>    <NONE>    <NONE>
 EXT_NW     GYPSMSAND WOOD_LATH INSUL_R10 TRCRETE   <NONE>    <NONE>
 EXT_NE     GYPSMSAND WOOD_LATH INSUL_R10 TRCRETE   <NONE>    <NONE>
 EXT_SW     GYPSMSAND WOOD_LATH INSUL_R10 TRCRETE   <NONE>    <NONE>
 EXT_SE     TRCRETE   <NONE>    <NONE>    <NONE>    <NONE>    <NONE>
 ROOF       CEILING   <NONE>    <NONE>    <NONE>    <NONE>    <NONE>
 GFLOOR     CONC75    STONE1    R-2.022   <NONE>    <NONE>    <NONE>
```

```
Scenario 3, R10 insulation applied
PARVAK, PVR10_3 revised: 9/30/96
WALL.TYPES
*   WALL      LAYER     LAYER     LAYER     LAYER     LAYER     LAYER
*   TYPE       # 1       # 2       # 3       # 4       # 5       # 6
*AAAAAAAAAA AAAAAAAAA AAAAAAAAA AAAAAAAAA AAAAAAAAA AAAAAAAAA AAAAAAAAA
```

```
 DOOR        WOOD      <NONE>    <NONE>    <NONE>    <NONE>    <NONE>
 CORRI/OCC   TRCRETE   <NONE>    <NONE>    <NONE>    <NONE>    <NONE>
 SHRD_OCCUP  TRCRETE   <NONE>    <NONE>    <NONE>    <NONE>    <NONE>
 EXT_NW      GYPSMSAND WOOD_LATH INSUL_R10 TRCRETE   <NONE>    <NONE>
 EXT_NE      GYPSMSAND WOOD_LATH INSUL_R10 TRCRETE   <NONE>    <NONE>
 EXT_SW      GYPSMSAND WOOD_LATH INSUL_R10 TRCRETE   <NONE>    <NONE>
 EXT_SE      GYPSMSAND WOOD_LATH INSUL_R10 TRCRETE   <NONE>    <NONE>
 ROOF        GYPSMSAND WOOD_LATH INSUL_R10 CEILING   <NONE>    <NONE>
 GFLOOR      CONC75    STONE1    R-2.022   <NONE>    <NONE>    <NONE>

Scenario 4, R10 insulation applied
R-10 on Ext & Occ/Corridr walls, Parvak School, rev. 05/15/96
WALL.TYPES
*   WALL      LAYER     LAYER     LAYER     LAYER     LAYER     LAYER
*   TYPE       # 1       # 2       # 3       # 4       # 5       # 6
*AAAAAAAAAA AAAAAAAAA AAAAAAAAA AAAAAAAAA AAAAAAAAA AAAAAAAAA AAAAAAAAA
 DOOR        WOOD      <NONE>    <NONE>    <NONE>    <NONE>    <NONE>
 CORRI/OCC   GYPSMSAND WOOD_LATH INSUL_R10 TRCRETE   <NONE>    <NONE>
 SHRD_OCCUP  TRCRETE   <NONE>    <NONE>    <NONE>    <NONE>    <NONE>
 EXT_NW      GYPSMSAND WOOD_LATH INSUL_R10 TRCRETE   <NONE>    <NONE>
 EXT_NE      GYPSMSAND WOOD_LATH INSUL_R10 TRCRETE   <NONE>    <NONE>
 EXT_SW      GYPSMSAND WOOD_LATH INSUL_R10 TRCRETE   <NONE>    <NONE>
 EXT_SE      GYPSMSAND WOOD_LATH INSUL_R10 TRCRETE   <NONE>    <NONE>
 ROOF        CEILING   <NONE>    <NONE>    <NONE>    <NONE>    <NONE>
 GFLOOR      CONC75    STONE1    R-2.022   <NONE>    <NONE>    <NONE>

Scenario 7, R10 insulation applied
WALL.TYPES
*   WALL      LAYER     LAYER     LAYER     LAYER     LAYER     LAYER
*   TYPE       # 1       # 2       # 3       # 4       # 5       # 6
*AAAAAAAAAA AAAAAAAAA AAAAAAAAA AAAAAAAAA AAAAAAAAA AAAAAAAAA AAAAAAAAA
 DOOR        WOOD      <NONE>    <NONE>    <NONE>    <NONE>    <NONE>
 CORRI/OCC   GYPSMSAND WOOD_LATH INSUL_R10 TRCRETE   <NONE>    <NONE>
 SHRD_OCCUP  TRCRETE   <NONE>    <NONE>    <NONE>    <NONE>    <NONE>
```

```
 EXT_NW     GYPSMSAND WOOD_LATH INSUL_R10 TRCRETE   <NONE>    <NONE>
 EXT_NE     GYPSMSAND WOOD_LATH INSUL_R10 TRCRETE   <NONE>    <NONE>
 EXT_SW     GYPSMSAND WOOD_LATH INSUL_R10 TRCRETE   <NONE>    <NONE>
 EXT_SE     GYPSMSAND WOOD_LATH INSUL_R10 TRCRETE   <NONE>    <NONE>
 ROOF       GYPSMSAND WOOD_LATH INSUL_R10 CEILING   <NONE>    <NONE>
 CORR_ROOF  CEILING   <NONE>    <NONE>    <NONE>    <NONE>    <NONE>
 GFLOOR     CONC75    STONE1    R-2.022   <NONE>    <NONE>    <NONE>
```

```
Scenario 1, R5 insulation applied
R-5 on Ext Walls, winter input for Parvak School, rev. 05/15/96
WALL.TYPES
*   WALL       LAYER     LAYER     LAYER     LAYER     LAYER     LAYER
*   TYPE        # 1       # 2       # 3       # 4       # 5       # 6
*AAAAAAAAAA AAAAAAAAA AAAAAAAAA AAAAAAAAA AAAAAAAAA AAAAAAAAA AAAAAAAAA
 DOOR       WOOD      <NONE>    <NONE>    <NONE>    <NONE>    <NONE>
 CORRI/OCC  TRCRETE   <NONE>    <NONE>    <NONE>    <NONE>    <NONE>
 SHRD_OCCUP TRCRETE   <NONE>    <NONE>    <NONE>    <NONE>    <NONE>
 EXT_NW     GYPSMSAND WOOD_LATH INSUL_R5  TRCRETE   <NONE>    <NONE>
 EXT_NE     GYPSMSAND WOOD_LATH INSUL_R5  TRCRETE   <NONE>    <NONE>
 EXT_SW     GYPSMSAND WOOD_LATH INSUL_R5  TRCRETE   <NONE>    <NONE>
 EXT_SE     GYPSMSAND WOOD_LATH INSUL_R5  TRCRETE   <NONE>    <NONE>
 ROOF       CEILING   <NONE>    <NONE>    <NONE>    <NONE>    <NONE>
 GFLOOR     CONC75    STONE1    R-2.022   <NONE>    <NONE>    <NONE>
```

```
Scenario 2, R5 insulation applied
R-5 on Ext Walls Except SE, Parvak School, rev. 05/15/96
WALL.TYPES
*   WALL       LAYER     LAYER     LAYER     LAYER     LAYER     LAYER
*   TYPE        # 1       # 2       # 3       # 4       # 5       # 6
*AAAAAAAAAA AAAAAAAAA AAAAAAAAA AAAAAAAAA AAAAAAAAA AAAAAAAAA AAAAAAAAA
 DOOR       WOOD      <NONE>    <NONE>    <NONE>    <NONE>    <NONE>
 CORRI/OCC  TRCRETE   <NONE>    <NONE>    <NONE>    <NONE>    <NONE>
 SHRD_OCCUP TRCRETE   <NONE>    <NONE>    <NONE>    <NONE>    <NONE>
 EXT_NW     GYPSMSAND WOOD_LATH INSUL_R5  TRCRETE   <NONE>    <NONE>
```

```
 EXT_NE      GYPSMSAND WOOD_LATH INSUL_R5  TRCRETE   <NONE>    <NONE>
 EXT_SW      GYPSMSAND WOOD_LATH INSUL_R5  TRCRETE   <NONE>    <NONE>
 EXT_SE      TRCRETE   <NONE>    <NONE>    <NONE>    <NONE>    <NONE>
 ROOF        CEILING   <NONE>    <NONE>    <NONE>    <NONE>    <NONE>
 GFLOOR      CONC75    STONE1    R-2.022   <NONE>    <NONE>    <NONE>
```

```
Scenario 3, R5 insulation applied
PARVAK, PVR5_3 revised: 9/30/96
WALL.TYPES
*   WALL       LAYER     LAYER     LAYER     LAYER     LAYER     LAYER
*   TYPE        # 1       # 2       # 3       # 4       # 5       # 6
*AAAAAAAAAA AAAAAAAAA AAAAAAAAA AAAAAAAAA AAAAAAAAA AAAAAAAAA AAAAAAAAA
 DOOR        WOOD      <NONE>    <NONE>    <NONE>    <NONE>    <NONE>
 CORRI/OCC   TRCRETE   <NONE>    <NONE>    <NONE>    <NONE>    <NONE>
 SHRD_OCCUP  TRCRETE   <NONE>    <NONE>    <NONE>    <NONE>    <NONE>
 EXT_NW      GYPSMSAND WOOD_LATH INSUL_R5  TRCRETE   <NONE>    <NONE>
 EXT_NE      GYPSMSAND WOOD_LATH INSUL_R5  TRCRETE   <NONE>    <NONE>
 EXT_SW      GYPSMSAND WOOD_LATH INSUL_R5  TRCRETE   <NONE>    <NONE>
 EXT_SE      GYPSMSAND WOOD_LATH INSUL_R5  TRCRETE   <NONE>    <NONE>
 ROOF        GYPSMSAND WOOD_LATH INSUL_R5  CEILING   <NONE>    <NONE>
 GFLOOR      CONC75    STONE1    R-2.022   <NONE>    <NONE>    <NONE>
```

```
Scenario 4, R5 insulation applied
R-5 on Ext & Occ/Corridr walls, Parvak School, rev. 05/15/96 WALL.TYPES
*   WALL       LAYER     LAYER     LAYER     LAYER     LAYER     LAYER
*   TYPE        # 1       # 2       # 3       # 4       # 5       # 6
*AAAAAAAAAA AAAAAAAAA AAAAAAAAA AAAAAAAAA AAAAAAAAA AAAAAAAAA AAAAAAAAA
 DOOR        WOOD      <NONE>    <NONE>    <NONE>    <NONE>    <NONE>
 CORRI/OCC   GYPSMSAND WOOD_LATH INSUL_R5  TRCRETE   <NONE>    <NONE>
 SHRD_OCCUP  TRCRETE   <NONE>    <NONE>    <NONE>    <NONE>    <NONE>
 EXT_NW      GYPSMSAND WOOD_LATH INSUL_R5  TRCRETE   <NONE>    <NONE>
 EXT_NE      GYPSMSAND WOOD_LATH INSUL_R5  TRCRETE   <NONE>    <NONE>
 EXT_SW      GYPSMSAND WOOD_LATH INSUL_R5  TRCRETE   <NONE>    <NONE>
 EXT_SE      GYPSMSAND WOOD_LATH INSUL_R5  TRCRETE   <NONE>    <NONE>
```

```
 ROOF          CEILING    <NONE>     <NONE>     <NONE>     <NONE>     <NONE>
 GFLOOR        CONC75     STONE1     R-2.022    <NONE>     <NONE>     <NONE>

Scenario 7, R5 insulation applied
PARVAK, PVR5_7 revised: 9/30/96
WALL.TYPES
*   WALL        LAYER      LAYER      LAYER      LAYER      LAYER      LAYER
*   TYPE         # 1        # 2        # 3        # 4        # 5        # 6
*AAAAAAAAAA AAAAAAAAA AAAAAAAAA AAAAAAAAA AAAAAAAAA AAAAAAAAA AAAAAAAAA
 DOOR       WOOD      <NONE>     <NONE>     <NONE>     <NONE>     <NONE>
 CORRI/OCC  GYPSMSAND WOOD_LATH INSUL_R5   TRCRETE    <NONE>     <NONE>
 SHRD_OCCUP TRCRETE   <NONE>     <NONE>     <NONE>     <NONE>     <NONE>
 EXT_NW     GYPSMSAND WOOD_LATH INSUL_R5   TRCRETE    <NONE>     <NONE>
 EXT_NE     GYPSMSAND WOOD_LATH INSUL_R5   TRCRETE    <NONE>     <NONE>
 EXT_SW     GYPSMSAND WOOD_LATH INSUL_R5   TRCRETE    <NONE>     <NONE>
 EXT_SE     GYPSMSAND WOOD_LATH INSUL_R5   TRCRETE    <NONE>     <NONE>
 ROOF       GYPSMSAND WOOD_LATH INSUL_R5   CEILING    <NONE>     <NONE>
 CORR_ROOF  CEILING   <NONE>     <NONE>     <NONE>     <NONE>     <NONE>
 GFLOOR     CONC75    STONE1     R-2.022    <NONE>     <NONE>     <NONE>
```

12.5 Danyore baseline condition winter input file, revised 9/30/96

```
RUNS
*     RUN LABEL      STATION    GROUND GROUND -START- -STOP-- SKYLINE  PAR.
*                     NAME       REFL.  TEMP. MON DAY MON DAY PROFILE  TYPE
*                               [FRAC]   [C]  [DATE]  [DATE]
*AAAAAAAAAAAAAAAA AAAAAAAAAA S.SSSS SSS.SS AAA XX. AAA XX. AAAAAA  AAAAAA
 DAHNYORE         OCTOBER    0.2000 GROUND OCT  1. OCT 25. SKY     <NONE>
 DAHNYORE         NOVEMBER   0.2000 GROUND NOV  1. NOV 25. SKY     <NONE>
 DAHNYORE         DECEMBER   0.2000 GROUND DEC  1. DEC 25. SKY     <NONE>
 DAHNYORE         JANUARY    0.2000 GROUND JAN  1. JAN 25. SKY     <NONE>
 DAHNYORE         FEBRUARY   0.2000 GROUND FEB  1. FEB 25. SKY     <NONE>
 DAHNYORE         MARCH      0.2000 GROUND MAR  1. MAR 25. SKY     <NONE>
ZONES
*   ZONE       HVAC       FLOOR  HGT   INFIL.  SOLAR   SOLAR INTERNAL  LATENT
*   NAME       TYPE       AREA          RATE  TO AIR   LOST    GAIN     GAIN
*                         [SM]   [M]  [AC/H] [FRAC]  [FRAC]   [KW]     [KW]
*AAAAAAAAAA AAAAAAAAAA XXXXX.X XX.X SSS.SSS X.XXX  X.XXX SSSS.SSS SSSS.SSS
 CLASSROOM1 WOODSTOVE     44.6  2.7   1.5   0.15   0.04 CR-INT   CR-LAT
 CLASSROOM2 WOODSTOVE     44.6  2.7   1.5   0.15   0.04 CR-INT   CR-LAT
 CLASSROOM3 WOODSTOVE     44.6  2.7   1.5   0.15   0.04 CR-INT   CR-LAT
 CORRIDOR   <NONE>        36.6  2.7   1.5   0.15   0.03    0.       0.
WINDOWS
* INTERIOR   EXTERIOR   GLAZING    HEIGHT LENGTH --LOCATION--  EXTERIOR
*   ZONE     SURFACE     TYPE                    HORZ.  VERT.   ZONE
*                                    [M]    [M]    [M]    [M]
*AAAAAAAAAA AAAAAAAAAA AAAAAAAAAA XXX.XX XXX.XX XXXX.XX XXXX.XX AAAAAAAAAA
 CLASSROOM1 NORTHEAST  DOUBLE        1.3   1.02    0.48    0.61 AMBIENT
 CLASSROOM1 NORTHEAST  DOUBLE        1.3   1.02    2.46    0.61 AMBIENT
 CLASSROOM1 NORTHEAST  DOUBLE        1.3   1.02    4.44    0.61 AMBIENT
 CLASSROOM1 SOUTHWEST  DOUBLE        1.3   1.02    0.48    0.61 AMBIENT
 CLASSROOM1 SOUTHWEST  DOUBLE        1.3   1.02    2.46    0.61 AMBIENT
 CLASSROOM1 SOUTHWEST  DOUBLE        1.3   1.02    4.44    0.61 AMBIENT
 CLASSROOM1 OPENSKY    SINGLE        1.26  1.83    1.44    1.44 AMBIENT
```

```
 CLASSROOM2 NORTHEAST  DOUBLE        1.3    1.02     0.84     0.61 AMBIENT
 CLASSROOM2 NORTHEAST  DOUBLE        1.3    1.02     2.58     0.61 AMBIENT
 CLASSROOM2 NORTHEAST  DOUBLE        1.3    1.02     4.32     0.61 AMBIENT
 CLASSROOM2 NORTHEAST  DOUBLE        1.3    1.02     6.06     0.61 AMBIENT
 CLASSROOM2 OPENSKY    SINGLE        1.26   1.83     1.44     4.27 AMBIENT
 CLASSROOM3 SOUTHWEST  DOUBLE        1.3    1.02     2.16     0.61 AMBIENT
 CLASSROOM3 SOUTHWEST  DOUBLE        1.3    1.02     3.9      0.61 AMBIENT
 CLASSROOM3 SOUTHWEST  DOUBLE        1.3    1.02     5.64     0.61 AMBIENT
 CLASSROOM3 SOUTHWEST  DOUBLE        1.3    1.02     7.38     0.61 AMBIENT
 CLASSROOM3 OPENSKY    SINGLE        1.26   1.83     1.44     1.44 AMBIENT
 CORRIDOR   OPENSKY    SINGLE        2.4    1.26     4.08     0.48 AMBIENT
WALLS
*   WALL      --FRONT/INTERIOR SIDE--  --BACK/EXTERIOR SIDE---   WALL
*   TYPE        ZONE      SURF   SOLAR  ZONE OR    SURF  SOLAR    AREA
*               NAME      COEF   COEF.  SURFACE,   COEF  COEF.
*                         [W/C  [FRAC]  AMBIENT,   [W/C  [FRAC]   [SM]
*                         -SM]          GROUND     -SM]
*AAAAAAAAAA AAAAAAAAAA XX.XXX X.XXXX AAAAAAAAAA XX.XXX X.XXXX  XXXXX.X
 CEILING    CORRIDOR    8.278 <AREA> OPENSKY    22.7   <AREA>     38.6
 CEILING    CLASSROOM1  8.278 <AREA> OPENSKY    22.7   <AREA>     44.6
 CEILING    CLASSROOM2  8.278 <AREA> OPENSKY    22.7   <AREA>     44.6
 CEILING    CLASSROOM3  8.278 <AREA> OPENSKY    22.7   <AREA>     44.6
 EXT        CLASSROOM1  8.278 <AREA> NORTHWEST2 18.2   <AREA>     13.4
 EXT        CLASSROOM1  8.278 <AREA> NORTHEAST2 18.2   <AREA>     25.0
 CORRI/OCC  CLASSROOM1  8.278 <AREA> CORRIDOR    8.278 <AREA>     11.2
 DOOR       CLASSROOM1  8.278 <AREA> CORRIDOR    8.278 <AREA>      2.2
 EXT        CLASSROOM1  8.278 <AREA> SOUTHWEST2 18.2   <AREA>     25.0
 EXT        CLASSROOM2  8.278 <AREA> NORTHWEST  18.2   <AREA>     13.4
 EXT        CLASSROOM2  8.278 <AREA> NORTHEAST  18.2   <AREA>     25.0
 CORRI/OCC  CLASSROOM2  8.278 <AREA> CORRIDOR    8.278 <AREA>     11.2
 DOOR       CLASSROOM2  8.278 <AREA> CORRIDOR    8.278 <AREA>      2.2
 SHRD_OCCUP CLASSROOM2  8.278 <AREA> CLASSROOM3 18.2   <AREA>     25.0
 EXT        CLASSROOM3  8.278 <AREA> NORTHWEST   8.278 <AREA>     13.4
```

```
 CORRI/OCC    CLASSROOM3  8.278 <AREA> CORRIDOR    18.2    <AREA>     11.2
 DOOR         CLASSROOM3  8.278 <AREA> CORRIDOR    18.2    <AREA>      2.2
 EXT          CLASSROOM3  8.278 <AREA> SOUTHWEST   18.2    <AREA>     25.0
 EXT_CORRI    CORRIDOR    8.278 <AREA> NORTHWEST   18.2    <AREA>      0.8
 DOOR         CORRIDOR    8.278 <AREA> NORTHEAST   18.2    <AREA>      1.0
 EXT_CORRI    CORRIDOR    8.278 <AREA> NORTHWEST   18.2    <AREA>      0.5
 EXT_CORRI    CORRIDOR    8.278 <AREA> SOUTHWEST   18.2    <AREA>      0.7
 DOOR         CORRIDOR    8.278 <AREA> SOUTHWEST2  18.2    <AREA>      2.6
 EXT_CORRI    CORRIDOR    8.278 <AREA> SOUTHEAST   18.2    <AREA>     43.3
 GFLOOR       CORRIDOR    8.278 <AREA> GROUND      99.99   <AREA>     36.6
 GFLOOR       CLASSROOM1  8.278 <AREA> GROUND      99.99   <AREA>     44.6
 GFLOOR       CLASSROOM2  8.278 <AREA> GROUND      99.99   <AREA>     44.6
 GFLOOR       CLASSROOM3  8.278 <AREA> GROUND      99.99   <AREA>     44.6
SURFACES
*  SURFACE    COMPASS   TILT  HEIGHT   LENGTH  ---------  SHADING  ---------
*             AZIMUTH                          PARALLEL    LEFT       RIGHT
*                                                TYPE     PERPEND    PERPEND
*              [DEG]   [DEG]    [M]      [M]
*AAAAAAAAAA   XXX.X    XX.X XXXX.XX  XXXX.XX AAAAAAAAAA AAAAAAAAAA AAAAAAAAAA
 NORTHEAST     30.     90.     2.74     9.14 <NONE>     <NONE>     <NONE>
 NORTHWEST    300.     90.     2.74     4.88 <NONE>     <NONE>     <NONE>
 SOUTHWEST    210.     90.     2.74     9.14 <NONE>     <NONE>     <NONE>
 SOUTHEAST    120.     90.     2.74    15.81 <NONE>     <NONE>     <NONE>
 OPENSKY        0.      0.     9.14     4.88 <NONE>     <NONE>     <NONE>
 NORTHEAST2    80.     90.     2.74     9.14 <NONE>     <NONE>     <NONE>
 NORTHWEST2   350.     90.     2.74     4.88 <NONE>     <NONE>     <NONE>
 SOUTHWEST2   260.     90.     2.74     9.14 <NONE>     <NONE>     <NONE>
HVAC.TYPES
*   HVAC     HEATING  VENTING  COOLING  HEATING  VENTING  COOLING    COOLER
*   TYPE     SETPOINT SETPOINT SETPOINT CAPACITY CAPACITY CAPACITY     COIL
*              [C]      [C]      [C]      [KW]    [AC/H]    [KW]        [C]
*AAAAAAAAAA SSS.SSS  SSS.SSS  SSS.SSS  XXXX.XXX  XXX.XX  XXXX.XXX      XX.X
 WOODSTOVE  HEATING  <NONE>   <NONE>   <ADEQ>       0.        0.       12.8
```

```
WALL.TYPES
*   WALL       LAYER      LAYER      LAYER      LAYER      LAYER      LAYER
*   TYPE        # 1        # 2        # 3        # 4        # 5        # 6
*AAAAAAAAAA AAAAAAAAA  AAAAAAAAA  AAAAAAAAA  AAAAAAAAA  AAAAAAAAA  AAAAAAAAA
 DOOR       WOOD      <NONE>     <NONE>     <NONE>     <NONE>     <NONE>
 CORRI/OCC  HCCONCRET <NONE>     <NONE>     <NONE>     <NONE>     <NONE>
 SHRD_OCCUP HCCONCRET <NONE>     <NONE>     <NONE>     <NONE>     <NONE>
 EXT        HCCONCRET <NONE>     <NONE>     <NONE>     <NONE>     <NONE>
 EXT_CORRI  HCCONCRET <NONE>     <NONE>     <NONE>     <NONE>     <NONE>
 CEILING    ROOFMEAS  <NONE>     <NONE>     <NONE>     <NONE>     <NONE>
 GFLOOR     CONC75    STONE1     R-2.022    <NONE>     <NONE>     <NONE>
MASS.TYPES
*MASS TYPE   CONDUCTIVITY   DENSITY    SPECIFIC HEAT  THICKNESS  NODES
*               [W/M-C]     [KG/CM]     [KJ/KG-C]       [M]
*AAAAAAAAAA     X.XXXX     XXXX.XXX      X.XXXX       XX.XXXX    XX.
 CONC75         1.4        2100.         0.653         0.0762     1.
 HCCONCRET      0.6500     2272.         0.6533        0.203      1.
 INSUL_R5       0.0288       98.         1.339         0.0254     1.
 INSUL_R10      0.0288       98.         1.339         0.0508     1.
 GYPSMSAND      0.7999     1682.         0.8368        0.0127     1.
 ROOFMEAS       0.7247     2143.         0.8181        0.266      1.
 STONE1         1.73       2242.         0.837         0.127      1.
 WOOD           0.115       513.         2.64          0.0127     1.
 WOOD_LATH      0.115       513.         2.64          0.0064     1.
GLAZING.TYPES
* GLAZING    GLAZING   SHADING EXTINCTION  INDEX OF  THICKNESS  NUMBER
*  TYPE      U VALUE    COEF.     COEF.   REFRACTION OF LAYER     OF
*           [W/SM-C]   [FRAC]   [1/MM]      [NONE]     [MM]     LAYERS
*AAAAAAAAAA SS.SSSSS  SS.SSSSS  X.XXXX      X.XXXX    X.XXXX     XX.
 SINGLE      5.67      0.9      0.0197      1.5260    3.1750      1.
 DOUBLE      2.78      0.88     0.0197      1.5260    3.1750      2.
SKYLINE.TYPES
*SKYLINE  --------- ALTITUDE ANGLE OF SKYLINE [DEGREES] --------
```

```
*PROFILE   ---EAST------------------SOUTH-----------------WEST--
* NAME     100   80   60   40   20    0   20   40   60   80  100
*AAAAAA    XX.X XX.X XX.X XX.X XX.X XX.X XX.X XX.X XX.X XX.X XX.X
 SKY       18.  17.  15.  25.  27.  28.  25.  24.  19.  20.  30.
OUTPUTS
* OUTPUT    TIME   UNITS   OUTPUT    BUILDING   OUTPUT    FORMAT?
*  TYPE    PERIOD          SEASON    ELEMENT    SECTION
*          [H/D/M] [E/M]                                  [Y/N]
*AAAAAAAA    A       A    AAAAAAAA     XXXX.     XXXX.      A
 AMBIENT     M       M    <ALL>        <ALL>     <ALL>      Y
 BUILDING    D       M    <ALL>        <ALL>     <ALL>      Y
 ZONES       M       M    <ALL>        <ALL>     <ALL>      Y
SCHEDULES
*SCHEDULE  SEASON   HR   VALUE     HR   VALUE     HR   VALUE     HR   VALUE
*AAAAAAAA AAAAAAAA XX. XXXX.XXX   XX. XXXX.XXX   XX. XXXX.XXX   XX. XXXX.XXX
 HEATING  WINTER    7.   17.       15.    0.
 CR-INT   WINTER    7.    3.15     15.    0.
 CR-LAT   WINTER    7.    2.57     15.    0.
 GROUND   OCT       1.   27.4      24.   27.4
 GROUND   NOV       1.   26.7      24.   26.7
 GROUND   DEC       1.   22.1      24.   22.1
 GROUND   JAN       1.   15.9      24.   15.9
 GROUND   FEB       1.    9.2      24.    9.2
 GROUND   MAR       1.    4.3      24.    4.3
SEASONS
* SEASON      START DATE    STOP DATE    DAY OF WEEK
*  NAME         MON DAY      MON DAY    [ALL/M-F/S-S]
*AAAAAAAA       AAA XX.      AAA XX.        AAA
 WINTER         OCT  1.      MAR 31.        ALL
 OCT            OCT  1.      OCT 31.        ALL
 NOV            NOV  1.      NOV 30.        ALL
 DEC            DEC  1.      DEC 31.        ALL
 JAN            JAN  1.      JAN 31.        ALL
```

```
 FEB            FEB  1.      FEB 28.         ALL
 MAR            MAR  1.      MAR 31.         ALL
STATIONS
* STATION     LAT. LONG.  ELEV.  FILENAME   DATA  UNITS  -START-   -STOP--
*  NAME      [DEG] [DEG]  [M]               TYPE  [E/M]  MON DAY   MON DAY
*AAAAAAAAAA XX.XX XXX.X XXXXX. AAAAAAAAAA  XX.     A    AAA XX.   AAA XX.
 OCTOBER    35.91  71.8  1475. OCTOBER.R    3.     M    OCT  1.   OCT   30.
 NOVEMBER   35.91  71.8  1475. NOVEMBER.R   3.     M    NOV  1.   NOV   30.
 DECEMBER   35.91  71.8  1475. DECEMBER.R   3.     M    DEC  1.   DEC   30.
 JANUARY    35.91  71.8  1475. JANUARY.R    3.     M    JAN  1.   JAN   30.
 FEBRUARY   35.91  71.8  1475. FEBRUARY.R   3.     M    FEB  1.   FEB   28.
 MARCH      35.91  71.8  1475. MARCH.R      3.     M    MAR  1.   MAR   30.
END OF FILE
```


12.5.1 Alternative Danyore Simulation Scenarios

The following is a list of 12 alternative scenarios that were run for the Danyore School. These scenarios differ only in thermal insulation placement on the walls. Therefore only the Wall Types section of each alternative input file has been included. The first set of six scenarios utilize R10 insulation and the second set of six use R5 thermal insulation. Due to the fact that only a fraction of the actual school was simulated, there is not an external southeast wall and consequently Scenario 2 could not be simulated. Scenarios 1, 3b, 3, 4, 7b and 7 were simulated.

```
Scenario 1, R10 insulation applied
R-10 on Ext Walls, winter input for the Danyore School, revised 5/25/96
WALL.TYPES
*   WALL       LAYER     LAYER     LAYER     LAYER     LAYER     LAYER
*   TYPE        # 1       # 2       # 3       # 4       # 5       # 6
*AAAAAAAAAA AAAAAAAAA AAAAAAAAA AAAAAAAAA AAAAAAAAA AAAAAAAAA AAAAAAAAA
 DOOR       WOOD      <NONE>    <NONE>    <NONE>    <NONE>    <NONE>
 CORRI/OCC  HCCONCRET <NONE>    <NONE>    <NONE>    <NONE>    <NONE>
 SHRD_OCCUP HCCONCRET <NONE>    <NONE>    <NONE>    <NONE>    <NONE>
 EXT        GYPSMSAND WOOD_LATH INSUL_R10 HCCONCRET <NONE>    <NONE>
```

```
 EXT_CORRI   HCCONCRET <NONE>    <NONE>    <NONE>    <NONE>    <NONE>
 CEILING     ROOFMEAS  <NONE>    <NONE>    <NONE>    <NONE>    <NONE>
 GFLOOR      CONC75    STONE1    R-2.022   <NONE>    <NONE>    <NONE>
```

```
Scenario 3b, R10 insulation applied
Danyore DANR10_3b Winter Input File, revised 9/30/96
Inside surface of external walls for occupied rooms and all of the ceilings
WALL.TYPES
*   WALL       LAYER     LAYER     LAYER     LAYER     LAYER     LAYER
*   TYPE        # 1       # 2       # 3       # 4       # 5       # 6
*AAAAAAAAAA AAAAAAAAA AAAAAAAAA AAAAAAAAA AAAAAAAAA AAAAAAAAA AAAAAAAAA
 DOOR        WOOD      <NONE>    <NONE>    <NONE>    <NONE>    <NONE>
 CORRI/OCC   HCCONCRET <NONE>    <NONE>    <NONE>    <NONE>    <NONE>
 SHRD_OCCUP  HCCONCRET <NONE>    <NONE>    <NONE>    <NONE>    <NONE>
 EXT         GYPSMSAND WOOD_LATH INSUL_R10 HCCONCRET <NONE>    <NONE>
 EXT_CORRI   HCCONCRET <NONE>    <NONE>    <NONE>    <NONE>    <NONE>
 CEILING     GYPSMSAND WOOD_LATH INSUL_R10 ROOFMEAS  <NONE>    <NONE>
 GFLOOR      CONC75    STONE1    R-2.022   <NONE>    <NONE>    <NONE>
```

```
Danyore DANR10_3 Winter Input File, revised 9/30/96
Scenario 3, R10 insulation applied
WALL.TYPES
*   WALL       LAYER     LAYER     LAYER     LAYER     LAYER     LAYER
*   TYPE        # 1       # 2       # 3       # 4       # 5       # 6
*AAAAAAAAAA AAAAAAAAA AAAAAAAAA AAAAAAAAA AAAAAAAAA AAAAAAAAA AAAAAAAAA
 DOOR        WOOD      <NONE>    <NONE>    <NONE>    <NONE>    <NONE>
 CORRI/OCC   HCCONCRET <NONE>    <NONE>    <NONE>    <NONE>    <NONE>
 SHRD_OCCUP  HCCONCRET <NONE>    <NONE>    <NONE>    <NONE>    <NONE>
 EXT         GYPSMSAND WOOD_LATH INSUL_R10 HCCONCRET <NONE>    <NONE>
 EXT_CORRI   HCCONCRET <NONE>    <NONE>    <NONE>    <NONE>    <NONE>
 CEILING     GYPSMSAND WOOD_LATH INSUL_R10 ROOFMEAS  <NONE>    <NONE>
 CORR_CEIL   HCCONCRET ROOFMEAS  <NONE>    <NONE>    <NONE>    <NONE>
 GFLOOR      CONC75    STONE1    R-2.022   <NONE>    <NONE>    <NONE>
```

```
Scenario 4, R10 insulation applied
R-10 on Ext & Occ/Corridr walls, Danyore School, revised 5/25/96
WALL.TYPES
*   WALL       LAYER     LAYER     LAYER     LAYER     LAYER     LAYER
*   TYPE        # 1       # 2       # 3       # 4       # 5       # 6
*AAAAAAAAAA AAAAAAAAA AAAAAAAAA AAAAAAAAA AAAAAAAAA AAAAAAAAA AAAAAAAAA
 DOOR       WOOD      <NONE>    <NONE>    <NONE>    <NONE>    <NONE>
 CORRI/OCC  GYPSMSAND WOOD_LATH INSUL_R10 HCCONCRET <NONE>    <NONE>
 SHRD_OCCUP HCCONCRET <NONE>    <NONE>    <NONE>    <NONE>    <NONE>
 EXT        GYPSMSAND WOOD_LATH INSUL_R10 HCCONCRET <NONE>    <NONE>
 EXT_CORRI  HCCONCRET <NONE>    <NONE>    <NONE>    <NONE>    <NONE>
 CEILING    ROOFMEAS  <NONE>    <NONE>    <NONE>    <NONE>    <NONE>
 GFLOOR     CONC75    STONE1    R-2.022   <NONE>    <NONE>    <NONE>
```

```
Scenario 7b, R10 insulation applied
Danyore DANR10_7b Winter Input File, revised 9/30/96
WALL.TYPES
*   WALL       LAYER     LAYER     LAYER     LAYER     LAYER     LAYER
*   TYPE        # 1       # 2       # 3       # 4       # 5       # 6
*AAAAAAAAAA AAAAAAAAA AAAAAAAAA AAAAAAAAA AAAAAAAAA AAAAAAAAA AAAAAAAAA
 DOOR       WOOD      <NONE>    <NONE>    <NONE>    <NONE>    <NONE>
 CORRI/OCC  GYPSMSAND WOOD_LATH INSUL_R10 HCCONCRET <NONE>    <NONE>
 SHRD_OCCUP HCCONCRET <NONE>    <NONE>    <NONE>    <NONE>    <NONE>
 EXT        GYPSMSAND WOOD_LATH INSUL_R10 HCCONCRET <NONE>    <NONE>
 EXT_CORRI  HCCONCRET <NONE>    <NONE>    <NONE>    <NONE>    <NONE>
 CEILING    GYPSMSAND WOOD_LATH INSUL_R10 ROOFMEAS  <NONE>    <NONE>
 GFLOOR     CONC75    STONE1    R-2.022   <NONE>    <NONE>    <NONE>
```

```
Scenario 7, R10 insulation applied
Danyore DANR10_7 Winter Input File, revised 9/30/96
WALL.TYPES
*   WALL       LAYER     LAYER     LAYER     LAYER     LAYER     LAYER
*   TYPE        # 1       # 2       # 3       # 4       # 5       # 6
*AAAAAAAAAA AAAAAAAAA AAAAAAAAA AAAAAAAAA AAAAAAAAA AAAAAAAAA AAAAAAAAA
```

```
 DOOR          WOOD        <NONE>      <NONE>      <NONE>      <NONE>     <NONE>
 CORRI/OCC     GYPSMSAND   WOOD_LATH   INSUL_R10   HCCONCRET   <NONE>     <NONE>
 SHRD_OCCUP    HCCONCRET   <NONE>      <NONE>      <NONE>      <NONE>     <NONE>
 EXT           GYPSMSAND   WOOD_LATH   INSUL_R10   HCCONCRET   <NONE>     <NONE>
 EXT_CORRI     HCCONCRET   <NONE>      <NONE>      <NONE>      <NONE>     <NONE>
 CEILING       GYPSMSAND   WOOD_LATH   INSUL_R10   ROOFMEAS    <NONE>     <NONE>
 CORR_CEIL     ROOFMEAS    <NONE>      <NONE>      <NONE>      <NONE>     <NONE>
 GFLOOR        CONC75      STONE1      R-2.022     <NONE>      <NONE>     <NONE>
```

Scenario 1, R5 insulation applied
R-5 on Ext Walls, winter input for Danyore School, revised 5/25/96

```
WALL.TYPES
*   WALL       LAYER       LAYER       LAYER       LAYER       LAYER      LAYER
*   TYPE        # 1         # 2         # 3         # 4         # 5        # 6
*AAAAAAAAAA AAAAAAAAA   AAAAAAAAA   AAAAAAAAA   AAAAAAAAA   AAAAAAAA   AAAAAAAA
 DOOR          WOOD        <NONE>      <NONE>      <NONE>      <NONE>     <NONE>
 CORRI/OCC     HCCONCRET   <NONE>      <NONE>      <NONE>      <NONE>     <NONE>
 SHRD_OCCUP    HCCONCRET   <NONE>      <NONE>      <NONE>      <NONE>     <NONE>
 EXT           GYPSMSAND   WOOD_LATH   INSUL_R5    HCCONCRET   <NONE>     <NONE>
 EXT_CORRI     HCCONCRET   <NONE>      <NONE>      <NONE>      <NONE>     <NONE>
 CEILING       ROOFMEAS    <NONE>      <NONE>      <NONE>      <NONE>     <NONE>
 GFLOOR        CONC75      STONE1      R-2.022     <NONE>      <NONE>     <NONE>
```

Scenario 3b, R5 insulation applied
Danyore DANR5_3b Winter Input File, revised 9/30/96

```
WALL.TYPES
*   WALL       LAYER       LAYER       LAYER       LAYER       LAYER      LAYER
*   TYPE        # 1         # 2         # 3         # 4         # 5        # 6
*AAAAAAAAAA AAAAAAAAA   AAAAAAAAA   AAAAAAAAA   AAAAAAAAA   AAAAAAAA   AAAAAAAA
 DOOR          WOOD        <NONE>      <NONE>      <NONE>      <NONE>     <NONE>
 CORRI/OCC     HCCONCRET   <NONE>      <NONE>      <NONE>      <NONE>     <NONE>
 SHRD_OCCUP    HCCONCRET   <NONE>      <NONE>      <NONE>      <NONE>     <NONE>
 EXT           GYPSMSAND   WOOD_LATH   INSUL_R5    HCCONCRET   <NONE>     <NONE>
 EXT_CORRI     HCCONCRET   <NONE>      <NONE>      <NONE>      <NONE>     <NONE>
```

```
 CEILING     GYPSMSAND WOOD_LATH INSUL_R5  ROOFMEAS  <NONE>    <NONE>
 GFLOOR      CONC75    STONE1    R-2.022   <NONE>    <NONE>    <NONE>
```

Scenario 3, R5 insulation applied
Danyore DANR5_3 Winter Input File, revised 9/30/96

```
WALL.TYPES
*   WALL       LAYER     LAYER     LAYER     LAYER     LAYER     LAYER
*   TYPE        # 1       # 2       # 3       # 4       # 5       # 6
*AAAAAAAAAA AAAAAAAAA AAAAAAAAA AAAAAAAAA AAAAAAAAA AAAAAAAA  AAAAAAAA
 DOOR        WOOD      <NONE>    <NONE>    <NONE>    <NONE>    <NONE>
 CORRI/OCC   HCCONCRET <NONE>    <NONE>    <NONE>    <NONE>    <NONE>
 SHRD_OCCUP  HCCONCRET <NONE>    <NONE>    <NONE>    <NONE>    <NONE>
 EXT         GYPSMSAND WOOD_LATH INSUL_R5  HCCONCRET <NONE>    <NONE>
 EXT_CORRI   HCCONCRET <NONE>    <NONE>    <NONE>    <NONE>    <NONE>
 CEILING     GYPSMSAND WOOD_LATH INSUL_R5  ROOFMEAS  <NONE>    <NONE>
 COR_CEILNG  ROOFMEAS  <NONE>    <NONE>    <NONE>    <NONE>    <NONE>
 GFLOOR      CONC75    STONE1    R-2.022   <NONE>    <NONE>    <NONE>
```

Scenario 4, R5 insulation applied
R-5 on Ext & Occ/Corridr walls, Danyore School, revised 5/25/96

```
WALL.TYPES
*   WALL       LAYER     LAYER     LAYER     LAYER     LAYER     LAYER
*   TYPE        # 1       # 2       # 3       # 4       # 5       # 6
*AAAAAAAAAA AAAAAAAAA AAAAAAAAA AAAAAAAAA AAAAAAAAA AAAAAAAA  AAAAAAAA
 DOOR        WOOD      <NONE>    <NONE>    <NONE>    <NONE>    <NONE>
 CORRI/OCC   GYPSMSAND WOOD_LATH INSUL_R5  HCCONCRET <NONE>    <NONE>
 SHRD_OCCUP  HCCONCRET <NONE>    <NONE>    <NONE>    <NONE>    <NONE>
 EXT         GYPSMSAND WOOD_LATH INSUL_R5  HCCONCRET <NONE>    <NONE>
 EXT_CORRI   HCCONCRET <NONE>    <NONE>    <NONE>    <NONE>    <NONE>
 CEILING     ROOFMEAS  <NONE>    <NONE>    <NONE>    <NONE>    <NONE>
 GFLOOR      CONC75    STONE1    R-2.022   <NONE>    <NONE>    <NONE>
```

Scenario 7b, R5 insulation applied
Danyore DANR5_7b Winter Input File, revised 9/30/96

```
WALL.TYPES
*   WALL       LAYER      LAYER      LAYER      LAYER      LAYER     LAYER
*   TYPE        # 1        # 2        # 3        # 4        # 5       # 6
*AAAAAAAAAA AAAAAAAAA  AAAAAAAAA  AAAAAAAAA  AAAAAAAAA  AAAAAAAA  AAAAAAAA
 DOOR       WOOD       <NONE>     <NONE>     <NONE>     <NONE>    <NONE>
 CORRI/OCC  GYPSMSAND  WOOD_LATH  INSUL_R5   HCCONCRET  <NONE>    <NONE>
 SHRD_OCCUP HCCONCRET  <NONE>     <NONE>     <NONE>     <NONE>    <NONE>
 EXT        GYPSMSAND  WOOD_LATH  INSUL_R5   HCCONCRET  <NONE>    <NONE>
 EXT_CORRI  HCCONCRET  <NONE>     <NONE>     <NONE>     <NONE>    <NONE>
 CEILING    GYPSMSAND  WOOD_LATH  INSUL_R5   ROOFMEAS   <NONE>    <NONE>
 GFLOOR     CONC75     STONE1     R-2.022    <NONE>     <NONE>    <NONE>
```

```
Scenario 7, R5 insulation applied
Danyore DANR5_7 Winter Input File, revised 9/30/96
WALL.TYPES
*   WALL       LAYER      LAYER      LAYER      LAYER      LAYER     LAYER
*   TYPE        # 1        # 2        # 3        # 4        # 5       # 6
*AAAAAAAAAA AAAAAAAAA  AAAAAAAAA  AAAAAAAAA  AAAAAAAAA  AAAAAAAA  AAAAAAAA
 DOOR       WOOD       <NONE>     <NONE>     <NONE>     <NONE>    <NONE>
 CORRI/OCC  GYPSMSAND  WOOD_LATH  INSUL_R5   HCCONCRET  <NONE>    <NONE>
 SHRD_OCCUP HCCONCRET  <NONE>     <NONE>     <NONE>     <NONE>    <NONE>
 EXT        GYPSMSAND  WOOD_LATH  INSUL_R5   HCCONCRET  <NONE>    <NONE>
 EXT_CORRI  HCCONCRET  <NONE>     <NONE>     <NONE>     <NONE>    <NONE>
 CEILING    GYPSMSAND  WOOD_LATH  INSUL_R5   ROOFMEAS   <NONE>    <NONE>
 CORR_CEIL  ROOFMEAS   <NONE>     <NONE>     <NONE>     <NONE>    <NONE>
 GFLOOR     CONC75     STONE1     R-2.022    <NONE>     <NONE>    <NONE>
```

13. Supporting Material for the Site Surveys

13.1 Brief Travel Log for Trip to Northern Areas and Chitral, Pakistan, 11/18/95 to 11/28/95

This travel log covers some of the precautions and contacts that helped ensure the success of a 10-day site survey trip I made in November, 1995 to the Northern Areas and Chitral, Pakistan. It is intended to be a brief source of information for people planning similar types of trips. It is not intended to be an exhaustive guide listing everything you need to know.

13.1.1 General Tips for Respecting the Islamic Culture in the Northern Areas

It is important to respect the culture which includes:

- do not expose bare skin (arms, legs, etc..).
- do not comment on a female's beauty (be she child or woman)
- do not assume western greetings with Muslim women by extending your hand out towards a woman unless she first extends hers. However with men, expect a hearty two-handed shake and maybe a hug once you know them
- religion is taken very seriously
- expect to have tea several times a day, it is an expression of welcoming and community
-

13.1.2 Health Precautions

I ended up getting some kind of flu and upper respiratory irritation. Bring something like aspirin for fever. These areas are extremely dusty, especially if you are traveling by or near the roads (which are predominantly made of dirt). I would suggest at least bringing some type of scarf for these situations; I will bring a dust mask next time. I probably took the maximum protection except for a flu shot which might have helped me. Although I didn't get diarrhea, I would strongly suggest that you take along Immodium AD. Only drink bottled water. If you afraid of eating uncertain meats, a good plan would be to claim you are a vegetarian.

13.1.2.1 Vaccinations and Immunizations

Disclaimer: This list is neither exhaustive nor up to date. I am not a doctor and provide this information to make you aware of my experience.

What was suggested by MIT medical staff:

- Polio Booster
- Tetanus Shot
- Gammagobulin
- Live Typhoid Vaccine
- Malaria medicine (Larium)
- antibiotic for severe diarrhea

13.1.2.2 Food & Water

It is suggested that all water be bottled and that only cooked foods be consumed.

13.1.3 Contacts at the AKHBP, Gilgit Housing Office

These two people were extremely helpful!

Rahmat Ali,
General Manager, Northern Areas; and

Karimulla Beg,
Administrative Officer, Northern Areas

AKHBP,
PO Box 526,
Gilgit,
Northern Areas,
Pakistan.
Tel:0572-2499
0572-3501
Fax:0572-2824

13.2 Task List for School Site Survey

<u>Task List for Schools in Pakistan</u>

Check off when task completed - Note observations

School Name: Location:

1. Measure light levels outside and inside, compass/orientation
2. Elevation profile measurements
3. Elevation of obstructions
4. Note Weather, Cloudiness Type, and Wind
5. Choose a wind shield factor - photograph the site
6. Record Dry & Wet Bulb temp. inside rooms and outdoors
7. Surveys - use audio recorder
8. Choose sensor locations (check with teacher for potential hazards)
9. Place sensors - Record location of placement
10. Explain use of humidity tools in schools
11. Measure thermal properties of walls, roofs, doors and windows
12. Qualitative assessment of doors and windows.
13. Check for fires & pilot lights, Blower door test
14. Calculation for natural infiltration rate
15. Based on number of occupants decide whether to weatherize
16. If there was a need to weatherize, repeat blower door test
17. Check the ceiling insulation
18. Photograph rooms if possible

13.3 Summaries of Completed Occupant Surveys for the Ahmedabad, Ghakuch, Danyore, and Parvak Self-Help Schools

Ghakuch - Summary of 7 Room Overviews: Teacher

Answers are underlined and in bold text.

Italicized numbers/comments are shown in parentheses where applicable

This form need only be filled in once for each classroom or office.

Name of School: Ghakuch

Ages of your pupils: 8 to 14 How many people in your room? avg. 21

Your Name: Position: teacher Date: 11/23/95

Please indicate the location of the room you are in by circling the appropriate specifications:

<u>Classroom</u> Corridor Office

The room has windows facing: (*circle all that apply*)

North Northeast East Southeast South Southwest West Northwest

1. Circle the condition which best describes the heating of the room you are in:
   No Heat Open Fire **<u>Stove</u>** Electric Heater
2. Is there generally smoke in the room? Large Amount **<u>Average</u>** None
   If yes, is it visible? (*circle all that apply)* **<u>Above Head</u>** Head Level
   Below Head Level
3. Are there artificial lights in the classroom? Yes **<u>No</u>**
4. Are there any skylights in the room? **<u>Yes</u>** No How many? 0 **<u>1</u>** 2 3 4 5 Do the skylights let in enough light? *(2/7 Rooms with windows facing South and East)***<u>Yes</u>** *(5/7)***<u>No</u>** Do the skylights let in too much heat? Yes **<u>No</u>** Do the skylights leak? Yes **<u>No</u>**
5. Are the windows too bright? **<u>Yes</u>** No
6. Is there enough light on the blackboard? *(6/7)***<u>Yes</u>** *(1/7 Room with South windows)***<u>No</u>**
7. Does the roof leak? *(4/7)***<u>Yes</u>** *(3/7)* **<u>No</u>**
8. Does water run onto the walls when it rains? Always *(2/7-Both noted that water leaks around the roof beams when it rains)***<u>Sometimes</u>** *(5/7)***<u>Never</u>**
   If it does, how much? Streams Everywhere *(1/7 - Room with East facing windows who answered Never to the first part)* **<u>Streams in Spots</u>**
   (2/7 - Both rooms have Northeast facing windows) **<u>Streams in 1 or 2 Places</u>**
   Moisture Everywhere Moisture in Spots
9. Does intrusive noise regularly come into the classroom from other rooms? Yes **<u>No</u>**
10. Do the walls feel unusually cold in the winter?
    *(1/7 - Rm with NE windows)***<u>Yes</u>** *(6/7)* **<u>No</u>**
11. Does the floor feel unusually cold in the winter?
    (1/7 - Rm with NE windows) **<u>Yes</u>** *(6/7)***<u>No</u>**
    Are there mats on the floor? Yes **<u>No</u>**

12. Does the classroom stay fairly cool in the summer?

(2/7 Rooms with East and Northeast facing windows) **<u>Yes</u>** *(6/7)***<u>No</u>**

13. Do you use the walls for display purposes? **<u>Yes</u>** No

14. In winter, is the classroom door open? Always *(3/7 - Rooms with Northeast windows)***<u>Usually</u>** Rarely *(4/7)***<u>Never</u>**

How open is it? 100%75% *(6/6 - makes me think this question was misinterpreted by some)***<u>50%</u>** 0% Depends on the noise level from other classrooms

15. Is overheating a problem in the summer? Yes **<u>No</u>**

Ghakuch - Summary of 6 Regularly Scheduled Occupied Space Surveys: Teacher

Answers are underlined and in bold text.

Italicized numbers/comments are shown in parentheses where applicable

This form should be filled in at least once a month (or more frequently if it is not too disruptive) for each occupied space (this may include the corridor). The completed forms should be returned to MIT with a diskette of the monthly temperature data from the loggers (or the manual log sheets from the Radio Shack monitors). One person can summarize the responses of the class.

Name of School: Ghakuch
Name of Teacher (*if this is a classroom*):
Your Name: Position: teacher
Time: 1-2 p.m. Date: 11/23/95
Please indicate the location of the room you are in by circling the appropriate specifications:
Classroom Corridor Office
The room has windows facing: (*Circle all that apply*)
North Northeast East Southeast South Southwest West Northwest

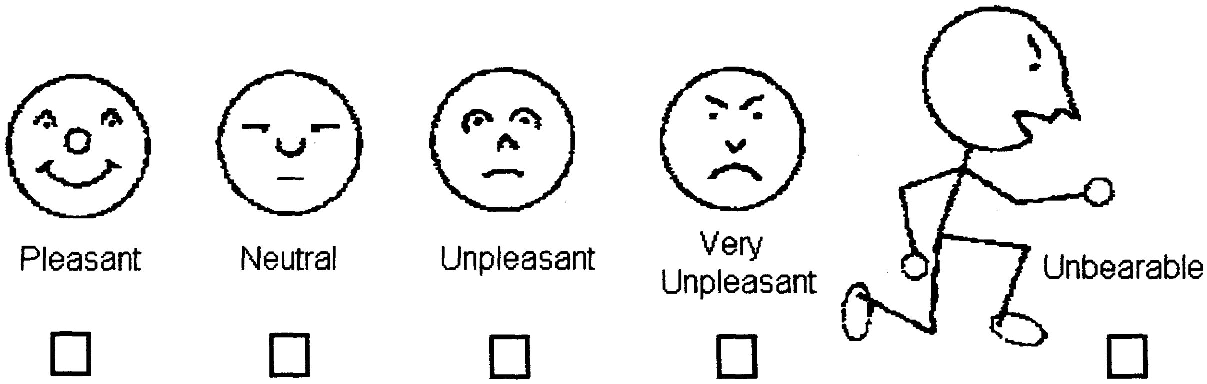
1. Are there artificial lights in the classroom? Yes **No**
   If yes, are they turned on right now? Yes No
2. How many people are in the room right now? avg. 21.2
3. Is the door to the room? Closed **25% Open** 50% Open 75% Open Open
4. Are the windows? Closed **25% Open** 50% Open 75% Open Open
5. What is the weather like outside? (*Circle all that apply*)
   *(3/6)***Sunny** *(3/6)***Partly Cloudy** Cloudy Heavy Rain Light Rain Sleet Light Snow Heavy Snow Extremely Cold Very Cold Cold **Slightly Cold** Neutral Slightly Warm
6. Is there moisture condensing on any surface? (*Circle all that apply*)
   No Moisture Outside Walls Internal Walls **Windows** Ceiling
7. I feel... Slightly Cold Too Cold *(6/6)***Extremely Cold** Extremely Warm Too Warm *(2/6 also checked this one)***Slightly Warm** Just Right
8. My feet are... *(4/6)***Extremely Warm** Too Warm *(2/6)***Slightly Warm** Just Right Slightly Cold Too Cold *(4/6)***Extremely Cold**
9. My head is... *(2/6)***Extremely Warm** Too Warm Slightly Warm Just Right Slightly Cold Too Cold *(6/6)***Extremely Cold**
   (Note that the diametrically opposed double responses in questions 7,8 & 9 such as "my head is both extremely warm and extremely cold suggests that some respondents did not understand the adjective "Extremely")
10. The air feels...(*Circle all that apply*)
    *(1/6)***Stuffy** Draughts Humid Very Humid *(5/6)***Dry** Very Dry Cold *(3/6)***Cool** Neutral Warm Hot *(3/6)***Normal** Unusual
11. Is it difficult to breathe? Yes A little **Not at**
    Is there enough light in the classroom? **Yes** No

Do you feel a draught? **Yes** No

If yes, where is it coming from? (*Circle all that apply*)

Door **Windows** Ceiling **Walls**

12. Have you ever been hurt by the roughness of the walls? Yes **No**
13. Do you lean against the walls? Often Sometimes Rarely **Never**
14. Do you bump into the walls as you are walking by?
    Often Sometimes Rarely **Never**
15. Choose the face which best describes how the air in your classroom smells?



6 out of 6 said Neutral

Ahmedabad - Summary of 6 Room Overviews: Teacher

Answers are underlined and in bold text; Percentages are used where applicable

This form need only be filled in once for each classroom or office.

Name of School: D.J. Middle Ahmedabad, Hunza

Ages of your pupils: 8 to 13 How many people in your room? 30.3

Your Name: Position: teacher Date: 11/21/95

Please indicate the location of the room you are in by circling the appropriate specifications:

100% **Classroom** Corridor Office

The room has windows facing: (*circle all that apply*)

North Northeast East Southeast South Southwest West Northwest

1. Circle the condition which best describes the heating of the room you are in:
   No Heat Open Fire **Stove** Electric Heater
2. Is there generally smoke in the room? Large Amount *(50%)* **Average** *(50%)* **None**
   If yes, is it visible? (*circle all that apply*) *(50%)* **Above Head** Head Level Below Head Level
3. Are there artificial lights in the classroom? **Yes** No
4. Are there any skylights in the room? **Yes** No How many? 0 1 **2** 3 4 5 Do the skylights let in enough light? **Yes** No Do the skylights let in too much heat? Yes **No** Do the skylights leak? Yes **No**
5. Are the windows too bright? **Yes** No
6. Is there enough light on the blackboard? **Yes** No
7. Does the roof leak? Yes **No**
8. Does water run onto the walls when it rains? *(50% did not respond)* Always *(50%)***Sometimes** Never
   If it does, how much? Streams Everywhere *(50%)***Streams in Spots** *(50%)***Streams in 1 or 2 Places** Moisture Everywhere Moisture in Spots
9. Does intrusive noise regularly come into the classroom from other rooms? **Yes** No
10. Do the walls feel unusually cold in the winter? (83%)**Yes** (16.7%)**No**
11. Does the floor feel unusually cold in the winter? **Yes** No
    Are there mats on the floor? Yes **No**
12. Does the classroom stay fairly cool in the summer? (83%)**Yes** (16.7%)**No**
    NOTE: Question 13 seems to have been answered incorrectly by most people when compared to question 15 responses and verbal interviews. They may have read summer as winter due to the fact that 9,10, &11 are winter questions.
13. Do you use the walls for display purposes? **Yes** No
14. In winter, is the classroom door open? Always Usually Rarely **Never**
    How open is it? 100% 75% 50% 0% Depends on the noise level from other classrooms
15. Is overheating a problem in the summer? **Yes** No

Regularly Scheduled Occupied Space Survey

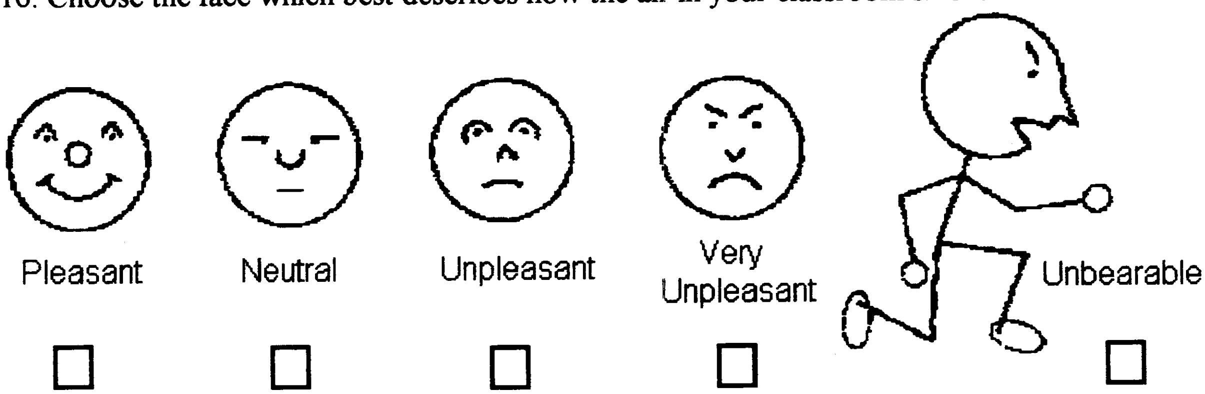
This form should be filled in at least once a month (or more frequently if it is not too disruptive) for each occupied space (this may include the corridor). The completed forms should be returned to MIT with a diskette of the monthly temperature data from the loggers (or the manual log sheets from the Radio Shack monitors) . One person can summarize the responses of the class.

Name of School:
Name of Teacher (*if this is a classroom*):
Your Name: Position:
Time: 12 noon Date: 11/21/95
Please indicate the location of the room you are in by circling the appropriate specifications:
100% **Classroom** Corridor Office
The room has windows facing: (*Circle all that apply*)
North Northeast East Southeast South Southwest West Northwest

1. Are there artificial lights in the classroom? **Yes** No
   If yes, are they turned on right now? Yes **No**
2. How many people are in the room right now? avg. 30.3
3. Is the door to the room? *(33% answered)* **Closed** *(33% answered)* **25% Open** *(33% answered)* **50% Open** 75% Open Open
4. Are the windows? *(33% answered)* **Closed** *(66.6% answered)* **25% Open** 50% Open 75% Open Open
5. What is the weather like outside? (*Circle all that apply*)
   Sunny Partly Cloudy Cloudy Heavy Rain Light Rain
   Sleet Light Snow Heavy Snow Extremely Cold Very Cold
   Cold Slightly Cold Neutral Slightly Warm
6. Is there moisture condensing on any surface? (*Circle all that apply*)
   No Moisture Outside Walls Internal Walls Windows Ceiling
7. I feel... Slightly Cold **Too Cold** Extremely Cold Extremely Warm
   Too Warm Slightly Warm Just Right
8. My feet are... Extremely Warm Too Warm Slightly Warm Just Right
   Slightly Cold **Too Cold** Extremely Cold
9. My head is... Extremely Warm Too Warm Slightly Warm Just Right
   Slightly Cold **Too Cold** Extremely Cold
10. The air feels...(*Circle all that apply*) Stuffy
    Draughts Humid Very Humid Dry Very Dry **Cold** Cool
    Neutral Warm Hot Normal Unusual
11. Is it difficult to breathe? Yes *(Only the classroom with East window with 21 13 yr.olds)* **A little** *(Only the classroom with 27 10 yr.olds)* **Not at All** ***(The other 4 classrooms did not answer this question)***
    Is there enough light in the classroom? *(66.6% answered)* **Yes** ***(1 with windows facing south and 1 with windows facing north and east)*** **No** ***(Both of these teachers***

answered that they each had 2 skylights which do let in enough light, that the windows were too bright, and that there is enough light on the blackboard)

12. Do you feel a draft? *(1 classroom did not answer)* *(83%)* **<u>Yes</u>** No
    If yes, where is it coming from? (*Circle all that apply*)
    (16.7% and this classroom. had the door 50% open) **<u>Door</u>** Windows
    (33%) **<u>Ceiling</u>** *(33%)* **<u>Walls</u>**
13. Have you ever been hurt by the roughness of the walls? Yes **<u>No</u>**
14. Do you lean against the walls? *(1 classroom did not answer)* Often Sometimes
    (83%) **<u>Rarely</u>** Never
15. Do you bump into the walls as you are walking by?
    Often Sometimes (16.7%, the classroom. w/27 10 yr. olds) **<u>Rarely</u>**
    (83%) **<u>Never</u>**
16. Choose the face which best describes how the air in your classroom smells?



<u>50% said Neutral</u>
<u>33% said Unpleasant</u>
<u>16.7% said Pleasant (classroom. with 27 10 year-olds)</u>

Parvak - Summary of 7 Room Overviews: Teacher

Answers are underlined and in bold text.

Italicized numbers/comments are shown in parentheses where applicable

This form need only be filled in once for each classroom or office.

Name of School: Ghakuch

Ages of your pupils: 11 to 14 and age 20 How many people in your room? avg. 17.1

Your Name: Position: teacher Date: 11/25/95

Please indicate the location of the room you are in by circling the appropriate specifications:

*(5/7)***<u>Classroom</u>** *(1/7)***<u>Corridor</u>** *(1/7)***<u>Office</u>**

The room has windows facing: (*circle all that apply*)

North Northeast East Southeast South Southwest West Northwest

1. Circle the condition which best describes the heating of the room you are in:
   No Heat Open Fire **<u>Stove</u>** Electric Heater
2. Is there generally smoke in the room? Large Amount *(6/7)***<u>Average</u>** *(1/7)***<u>None</u>**

If yes, is it visible? (*circle all that apply*) Above Head *(2/7)***<u>Head Level</u>**
Below Head Level

3. Are there artificial lights in the classroom? Yes **<u>No</u>**
4. Are there any skylights in the room? *(6/7)***<u>Yes</u>** *(1/7- The office)***<u>No</u>**
   How many? 0 *(6/7)***<u>1</u>** 2 3 4 5
   Do the skylights let in enough light? **<u>Yes</u>** No
   Do the skylights let in too much heat? Yes **<u>No</u>**
   Do the skylights leak? *(1/7)***<u>Yes</u>** *(6/7)***<u>No</u>**
5. Are the windows too bright? **<u>Yes</u>** No
6. Is there enough light on the blackboard? **<u>Yes</u>** No
7. Does the roof leak? Yes **<u>No</u>**
8. Does water run onto the walls when it rains? Always Sometimes **<u>Never</u>**
   If it does, how much? Streams Everywhere Streams in Spots
   Streams in 1 or 2 Places Moisture Everywhere Moisture in Spots
9. Does intrusive noise regularly come into the classroom from other rooms? Yes **<u>No</u>**
10. Do the walls feel unusually cold in the winter? *(3/7)***<u>Yes</u>** *(4/7)* **<u>No</u>**
11. Does the floor feel unusually cold in the winter? *(2/7)* **<u>Yes</u>** *(5/7)***<u>No</u>**
    Are there mats on the floor? Yes **<u>No</u>**
12. Does the classroom stay fairly cool in the summer? *(2/7 One of which is the office which doesn't have a skylight)* **<u>Yes</u>** *(4/7)***<u>No</u>**
    <u>NOTE: Question 13 seems to have been answered incorrectly by most people when compared to question 15 responses and verbal interviews. They may have read</u> <u>summer</u> *<u>as</u>* <u>winter</u> *<u>due to the fact that 9,10, &11 are winter questions.</u>*
13. Do you use the walls for display purposes? **<u>Yes</u>** No

In winter, what percentage of the time is the classroom door open? approximately 30%

Ghakuch - Summary of 6 Regularly Scheduled Occupied Space Surveys: Teacher

Answers are underlined and in bold text.

Italicized numbers/comments are shown in parentheses where applicable

This form should be filled in at least once a month (or more frequently if it is not too disruptive) for each occupied space (this may include the corridor). The completed forms should be returned to MIT with a diskette of the monthly temperature data from the loggers (or the manual log sheets from the Radio Shack monitors). One person can summarize the responses of the class.

Name of School: Ghakuch
Name of Teacher (*if this is a classroom*):
Your Name: Position: teacher
Time: 1-2 p.m. Date: 11/23/95
Please indicate the location of the room you are in by circling the appropriate specifications:
Classroom Corridor Office
The room has windows facing: (*Circle all that apply*)
North Northeast East Southeast South Southwest West Northwest

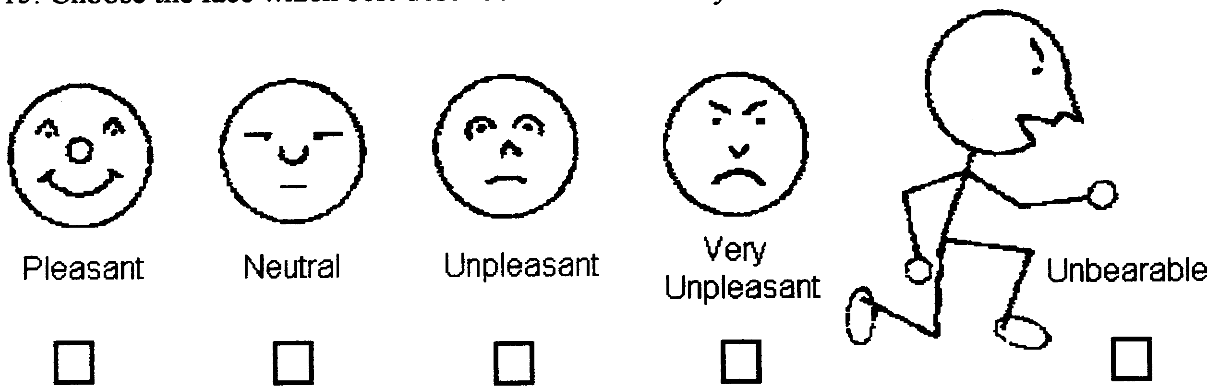
1. Are there artificial lights in the classroom? Yes **No**
   If yes, are they turned on right now? Yes No
2. How many people are in the room right now? avg. 21.2
3. Is the door to the room? Closed **25% Open** 50% Open 75% Open Open
4. Are the windows? Closed **25% Open** 50% Open 75% Open Open
5. What is the weather like outside? (*Circle all that apply*)
   *(3/6)***Sunny** *(3/6)***Partly Cloudy** Cloudy Heavy Rain Light Rain Sleet Light Snow Heavy Snow Extremely Cold Very Cold Cold **Slightly Cold** Neutral Slightly Warm
6. Is there moisture condensing on any surface? (*Circle all that apply*)
   No Moisture Outside Walls Internal Walls **Windows** Ceiling
7. I feel... Slightly Cold Too Cold *(6/6)***Extremely Cold** Extremely Warm Too Warm *(2/6 also checked this one)***Slightly Warm** Just Right
8. My feet are... *(4/6)***Extremely Warm** Too Warm *(2/6)***Slightly Warm** Just Right Slightly Cold Too Cold *(4/6)***Extremely Cold**
9. My head is... *(2/6)***Extremely Warm** Too Warm Slightly Warm Just Right Slightly Cold Too Cold *(6/6)***Extremely Cold**
   (Note that the diametrically opposed double responses in questions 7,8 & 9 such as "my head is both extremely warm and extremely cold suggests that some respondents did not understand the adjective "Extremely")
10. The air feels...(*Circle all that apply*)
    *(1/6)***Stuffy** Draughts Humid Very Humid *(5/6)***Dry** Very Dry Cold *(3/6)***Cool** Neutral Warm Hot *(3/6)***Normal** Unusual
11. Is it difficult to breathe? Yes A little **Not at**
    Is there enough light in the classroom? **Yes** No

Do you feel a draught? **Yes** No

If yes, where is it coming from? (*Circle all that apply*)

Door **Windows** Ceiling **Walls**

12. Have you ever been hurt by the roughness of the walls? Yes **No**
13. Do you lean against the walls? Often Sometimes Rarely **Never**
14. Do you bump into the walls as you are walking by?
    Often Sometimes Rarely **Never**
15. Choose the face which best describes how the air in your classroom smells?



6 out of 6 said Neutral

Danyore - Summary of 7 Room Overviews: Teacher

Answers are underlined and in bold text.

Italicized numbers/comments are shown in parentheses where applicable

This form need only be filled in once for each classroom or office.

Name of School: Danyore

Ages of your pupils: 4 to 18 How many people in your room? avg. 57.3

Your Name: Position: teacher Date: 11/20/95

Please indicate the location of the room you are in by circling the appropriate specifications:

*(4/7)***Classroom** *(3/7 marked this, however all the classes we saw met outside or in a classroom)***Corridor** Office

The room has windows facing: (*circle all that apply*)

North Northeast East Southeast South Southwest West Northwest

1. Circle the condition which best describes the heating of the room you are in:
   *(4/7)***No Heat** Open Fire *(2/7)***Stove** *(1/7)***Electric Heater**
2. Is there generally smoke in the room? *(6/7 Including the 4 rooms who said "No Heat" in question 1 and the room with the "Electric Heater")***Large Amount** *(1/7)***Average** None
   If yes, is it visible? *(circle all that apply)* Above Head **Head Level** Below Head Level
3. Are there artificial lights in the classroom? **Yes** No
4. Are there any skylights in the room? **Yes** No How many? 0 **1** 2 3 4 5 Do the skylights let in enough light? *(3/7)***Yes** *(4/7)***No** Do the skylights let in too much heat? *(4/7)***Yes** *(3/7)***No** Do the skylights leak? *(6/7)***Yes** *(1/7)***No**
5. Are the windows too bright? *(2/7)***Yes** (5/7)**No**
6. Is there enough light on the blackboard? *(4/7)***Yes** *(3/7)***No**
7. Does the roof leak? *(5/7)***Yes** *(2/7)***No**
8. Does water run onto the walls when it rains? Always *(6/7)***Sometimes** *(1/7)***Never**
   If it does, how much? Streams Everywhere *(6/6)***Streams in Spot** Streams in 1 or 2 Places *(2/7)***Moisture Everywhere** *(1/7)***Moisture in Spots**
9. Does intrusive noise regularly come into the classroom from other rooms? Yes **No**
10. Do the walls feel unusually cold in the winter? **Yes** No
11. Does the floor feel unusually cold in the winter? **Yes** No
    Are there mats on the floor? Yes **No**
12. Does the classroom stay fairly cool in the summer? Yes **No**
13. Do you use the walls for display purposes? **Yes** No
14. In winter, is the classroom door open? Always *(1/7 - the corridor)***Usually** *(2/7)***Rarely** *(2/7)***Never**
    How open is it? *(1/7)***0%** *(2/7)***25%** 50% 75% *(1/7)***100%**

Ghakuch - Summary of 6 Regularly Scheduled Occupied Space Surveys: Teacher

Answers are underlined and in bold text.

Italicized numbers/comments are shown in parentheses where applicable

This form should be filled in at least once a month (or more frequently if it is not too disruptive) for each occupied space (this may include the corridor). The completed forms should be returned to MIT with a diskette of the monthly temperature data from the loggers (or the manual log sheets from the Radio Shack monitors) . One person can summarize the responses of the class.

Name of School: Ghakuch

Name of Teacher (*if this is a classroom*):

Your Name: Position: teacher

Time: 1-2 p.m. Date: 11/23/95

Please indicate the location of the room you are in by circling the appropriate specifications:

Classroom Corridor Office

The room has windows facing: (*Circle all that apply*)

North Northeast East Southeast South Southwest West Northwest

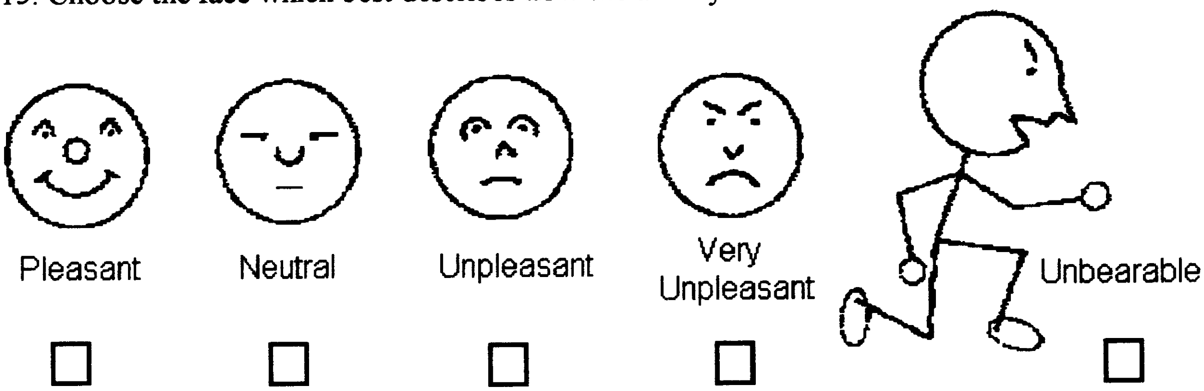
1. Are there artificial lights in the classroom? Yes **No**
   If yes, are they turned on right now? Yes No
2. How many people are in the room right now? avg. 21.2
3. Is the door to the room? Closed **25% Open** 50% Open 75% Open Open
4. Are the windows? Closed **25% Open** 50% Open 75% Open Open
5. What is the weather like outside? (*Circle all that apply*)
   *(3/6)***Sunny** *(3/6)***Partly Cloudy** Cloudy Heavy Rain Light Rain Sleet Light Snow Heavy Snow Extremely Cold Very Cold Cold **Slightly Cold** Neutral Slightly Warm
6. Is there moisture condensing on any surface? (*Circle all that apply*)
   No Moisture Outside Walls Internal Walls **Windows** Ceiling
7. I feel... Slightly Cold Too Cold *(6/6)***Extremely Cold** Extremely Warm Too Warm *(2/6 also checked this one)***Slightly Warm** Just Right
8. My feet are... *(4/6)***Extremely Warm** Too Warm *(2/6)***Slightly Warm** Just Right Slightly Cold Too Cold *(4/6)***Extremely Cold**
9. My head is... *(2/6)***Extremely Warm** Too Warm Slightly Warm Just Right Slightly Cold Too Cold *(6/6)***Extremely Cold**
   (Note that the diametrically opposed double responses in questions 7,8 & 9 such as "my head is both extremely warm and extremely cold suggests that some respondents did not understand the adjective "Extremely")
10. The air feels...(*Circle all that apply*)
    *(1/6)***Stuffy** Draughts Humid Very Humid *(5/6)***Dry** Very Dry Cold *(3/6)***Cool** Neutral Warm Hot *(3/6)***Normal** Unusual
11. Is it difficult to breathe? Yes A little **Not at**
    Is there enough light in the classroom? **Yes** No

Do you feel a draught? **Yes** No

If yes, where is it coming from? (*Circle all that apply*)

Door **Windows** Ceiling **Walls**

12. Have you ever been hurt by the roughness of the walls? Yes **No**
13. Do you lean against the walls? Often Sometimes Rarely **Never**
14. Do you bump into the walls as you are walking by?
    Often Sometimes Rarely **Never**
15. Choose the face which best describes how the air in your classroom smells?



6 out of 6 said Neutral

13.4 Blank Occupant Surveys

School Overview: Principal or Teacher

This form need only be filled out once for each school.

Name of School: Location: Age range of pupils:

Your Name: Position: Date:

I. Occupancy

1. How many people use the school on a daily basis?
2. How many people occupy each classroom?
3. What days of the week and what hours of the day is the school occupied?
4. What times of the year is the school occupied?

5. If the school was warmer in the winter, would the community prefer the school to be open during all of the winter months?

6. Is the corridor used as a classroom? Always Sometimes Rarely Never

II. Level of Conditioning

1. During what months and times of day is the school generally uncomfortable?

2. Do you burn fuel in the schools? Yes No
   What type of fuels? What is the schedule of use?
   Are the pupils expected to collect fuel? Yes No
   Is there ever a shortage of fuel? Always Every other day Once a Week Once every 2 weeks Once a month Never
3. Is there money set aside for heating fuel? Yes No
4. Does your school have electricity? Yes No
   What is it used for? What is the schedule of use?

Room Overview: Teacher

This form need only be filled in once for each classroom or office.

Name of School: Ages of your pupils: How many people in your room?

Your Name: Position: Date:

Please indicate the location of the room you are in by circling the appropriate specifications:

Classroom Corridor Office

The room has windows facing: (*circle all that apply*)

North Northeast East Southeast South Southwest West Northwest

1. Circle the condition which best describes the heating of the room you are in:
   No Heat Open Fire Stove Electric Heater
2. Is there generally smoke in the room? Large Amount Average None
   If yes, is it visible? (*circle all that apply*) Above Head Head Level Below Head Level
3. Are there artificial lights in the classroom? Yes No

4. Are there any skylights in the room? Yes No How many? 0 1 2 3 4 5 Do the skylights let in enough light? Yes No Do the skylights let in too much heat? Yes No Do the skylights leak? Yes No
5. Are the windows too bright? Yes No
6. Is there enough light on the blackboard? Yes No
7. Does the roof leak? Yes No
8. Does water run onto the walls when it rains? Always Sometimes Never

    If it does, how much? Streams Everywhere Streams in Spots Streams in 1 or 2 Places Moisture Everywhere Moisture in Spots
9. Does intrusive noise regularly come into the classroom from other rooms? Yes No
10. Do the walls feel unusually cold in the winter? Yes No
11. Does the floor feel unusually cold in the winter? Yes No

    Are there mats on the floor? Yes No
12. Does the classroom stay fairly cool in the summer? Yes No
13. Do you use the walls for display purposes? Yes No
14. In winter, is the classroom door open? Always Usually Rarely Never

    How open is it? 100% 75% 50% 0% Depends on the noise level from other classrooms
15. Is overheating a problem in the summer? Yes No

Regularly Scheduled Occupied Space Survey

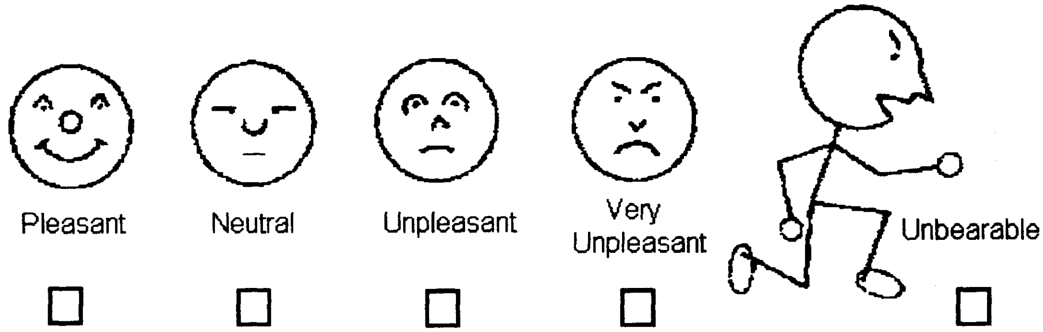
This form should be filled in at least once a month (or more frequently if it is not too disruptive) for each occupied space (this may include the corridor). The completed forms should be returned to MIT with a diskette of the monthly temperature data from the loggers (or the manual log sheets from the Radio Shack monitors). One person can summarize the responses of the class.

Name of School:
Name of Teacher (*if this is a classroom*):
Your Name: Position:
Time: Date:
Please indicate the location of the room you are in by circling the appropriate specifications:
Classroom Corridor Office
The room has windows facing: (*Circle all that apply*)
North Northeast East Southeast South Southwest West Northwest

1. Are there artificial lights in the classroom? Yes No
   If yes, are they turned on right now? Yes No
2. How many people are in the room right now?
3. Is the door to the room? Closed 25% Open 50% Open 75% Open Open
4. Are the windows? Closed 25% Open 50% Open 75% Open Open
5. What is the weather like outside? (*Circle all that apply*)
   Sunny Partly Cloudy Cloudy Heavy Rain Light Rain Sleet
   Light Snow Heavy Snow Extremely Cold Very Cold Cold
   Slightly Cold Neutral Slightly Warm
6. Is there moisture condensing on any surface? (*Circle all that apply*)
   No Moisture Outside Walls Internal Walls Windows Ceiling
7. I feel... Slightly Cold Too Cold Extremely Cold Extremely Warm
   Too Warm Slightly Warm Just Right
8. My feet are... Extremely Warm Too Warm Slightly Warm Just Right
   Slightly Cold Too Cold Extremely Cold
9. My head is... Extremely Warm Too Warm Slightly Warm Just Right
   Slightly Cold Too Cold Extremely Cold
10. The air feels...(*Circle all that apply*) Stuffy
    Draughts Humid Very Humid Dry Very Dry Cold Cool
    Neutral Warm Hot Normal Unusual
11. Is it difficult to breathe? Yes A little Not at All
    Is there enough light in the classroom? Yes No
12. Do you feel a draught? Yes No
    If yes, where is it coming from? (*Circle all that apply*)
    Door Windows Ceiling Walls
13. Have you ever been hurt by the roughness of the walls? Yes No
14. Do you lean against the walls? Often Sometimes Rarely Never
15. Do you bump into the walls as you are walking by?

Often Sometimes Rarely Never

16. Choose the face which best describes how the air in your classroom smells?



14. Tips for Getting Started with the SERI-RES Simulation Program

Weather data:
In the Runs and Stations sections of the input file one specifies the weather files to use. All the days in a file are the same for given month. Use a 10-day period from the 10th of the month to the 20th. The reason for this is that SERI-RES needs to stabilize on a baseline energy level before it can perform the analysis. For this reason, ignore the first three days or so in the output sections and probably just take the 10th day for each section. This is easily seen in the Whole House Temperatures section. For example:

WHOLE HOUSE TEMPERATURES

	MEAN	IN	MAX	RANGE
MON DY	C	C	C	C
DEC 10	12.47	8.4	18.1	9.7
DEC 11	6.59	5.0	8.2	3.2
DEC 12	4.89	3.8	5.9	2.1
DEC 13	4.37	3.4	5.3	1.9
DEC 14	4.20	3.3	5.2	1.9
DEC 15	4.15	3.3	5.1	1.8
DEC 16	4.13	3.3	5.1	1.8
DEC 17	4.12	3.3	5.1	1.8
DEC 18	4.12	3.2	5.1	1.8
DEC 19	4.12	3.2	5.1	1.8
DEC 20	4.12	3.2	5.1	1.8

The weather files I have prepared are labeled as shown in the following input section:

```
STATIONS
* STATION   LAT. LONG. ELEV. FILENAME DATA UNITS -START- -STOP--
* NAME     [DEG] [DEG]  [M]           TYPE [E/M] MON DAY MON DAY
*AAAAAAAAAA XX.XX XXX.X XXXXX. AAAAAAAAAA XX.  A  AAA XX.
 DEC-DAY   35.91  74.3  1469. DEC-DAY.R   3.   M  DEC 10.  DEC 20.
 FEB-DAY   35.91  74.3  1469. FEB-DAY.R   3.   M  FEB 10.  FEB 20.
 JAN-DAY   35.91  74.3  1469. JAN-DAY.R   3.   M  JAN 10.  JAN 20.
 MAR-DAY   35.91  74.3  1469. MAR-DAY.R   3.   M  MAR 10.  MAR 20.
 NOV-DAY   35.91  74.3  1469. NOV-DAY.R   3.   M  NOV 10.  NOV 20.
 OCT-DAY   35.91  74.3  1469. OCT-DAY.R   3.   M  OCT 10.  OCT 20.
```

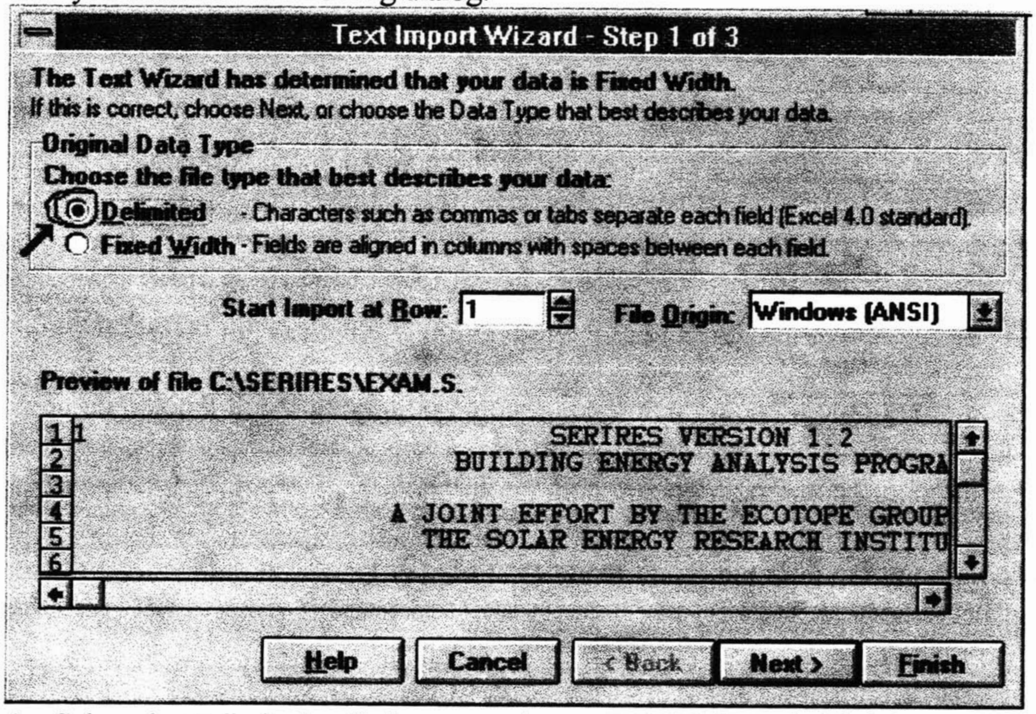
Use the manuals conventions for naming the files: i.e. .B input file, .C compiled file, .D machine/direct access summary output, .U unformatted file and .S for the summary file you will read.

The process is:
Compile your simulation file; run LOADS.EXE; run OUT.EXE

a) enter 'N' when OUT.EXE asks you whether to insert page breaks

2. After running OUT.EXE, switch over to MS Excel Ver. 5. The best process is to open it as a text file so that each line of the file is entered into the first column of each

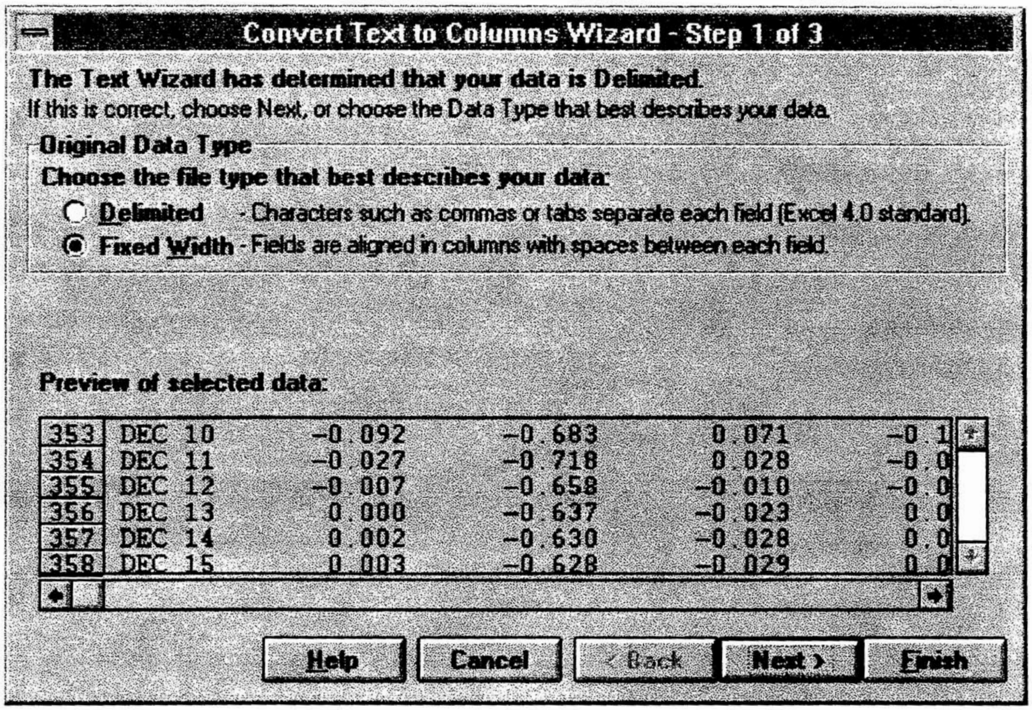
row. The way to do this is as follows-> say you entered TEST.S as the second file name in the OUT program then:
launch EXCEL;
go to File->Open, type in (your directory say? C:\SERIRES\) C:\SERIRES\TEST.S
then you will see the following dialog:



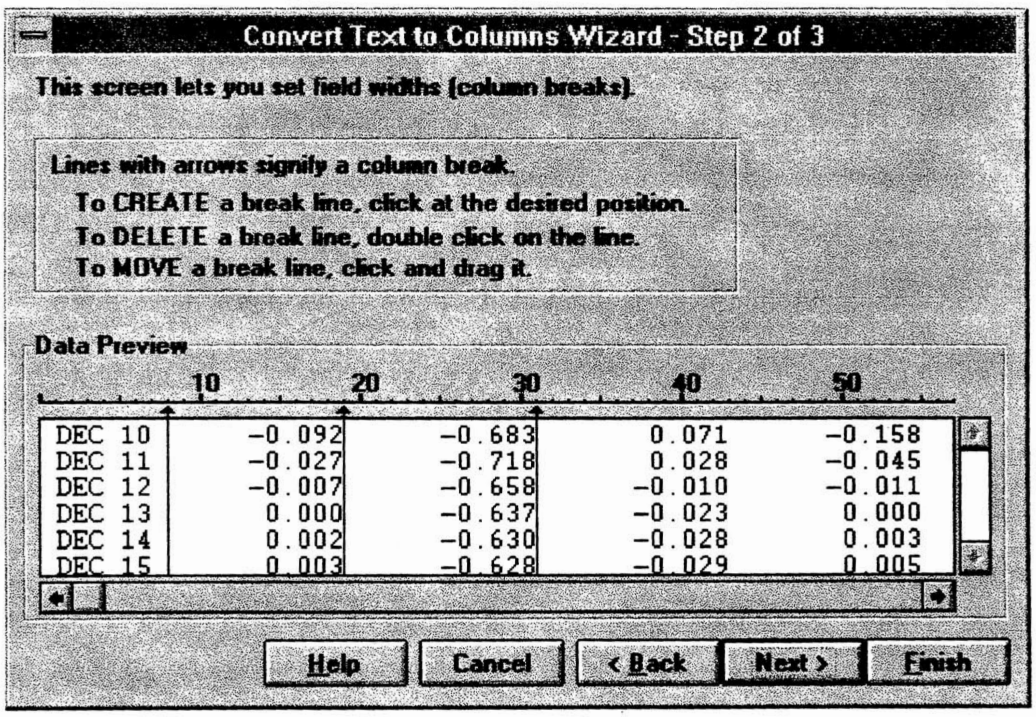
4. Select the Delimited radio button option and the click on the Finish button

Now the file is open with all your output in the first column of each row. The data is divided by sections more or less like the Output Sections described in the Appendix 2 of the manual; the first of which is a copy of your input file.

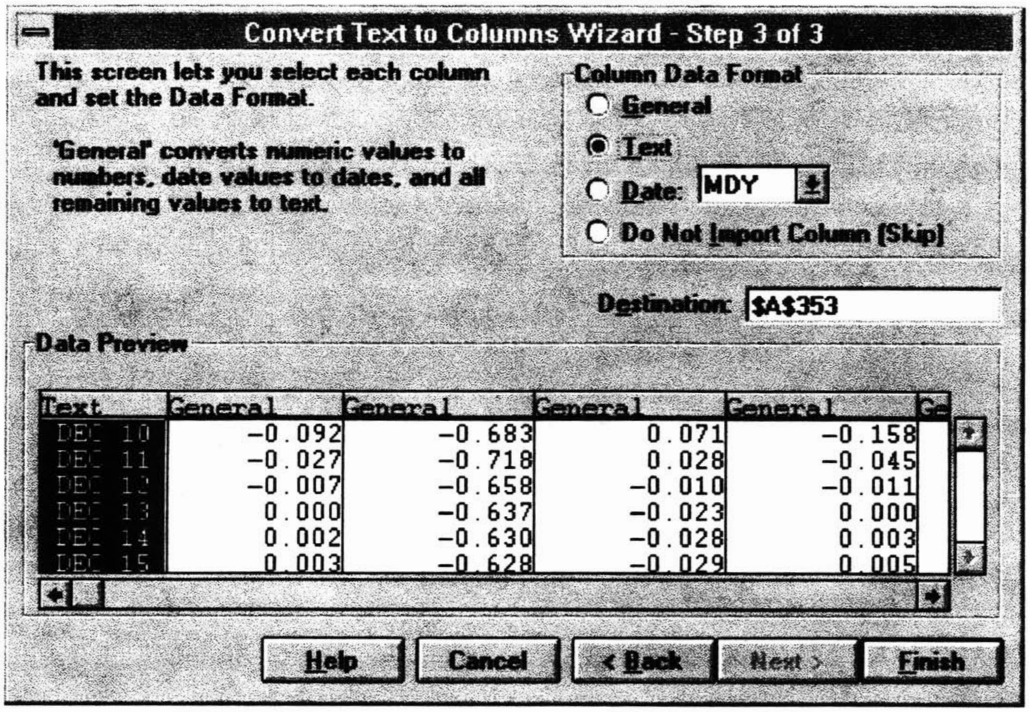
When you want to plot a section, or do some other spreadsheet function where you need your data separated into columns, you can simply:
select the first column of the rows you want
go to Data->Text to Columns... and you will see this dialog:



This time select the Fixed Width radio option and then the Next > button.
On the next dialog, you simply click inside the Preview box where you want the columns:



Finally, use the next dialog to format the columns in a particular manner or leave them as General.



One final note about the output is that if you do not specify some HVAC type in your zones, then you will see ZEROS in all of the Building Summary Statistics (directly following the input section of the output file) except for the exterior envelope. To generate useful data for the unheated condition in the occupied zones, specify an HVAC type with a Heat Set Point of 0 degrees for all zones except the corridor.

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Illustrations

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